Solar PV Plan Review& Inspections

(based on the 2021 *IRC/IFC*, and 2020/2023 *NEC*)

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West Coast Code Consultants

1

Doug Smith, MCP/CBO

- Inspector/Plan Reviewer for over 19 years
- 19 ICC certifications
- Certified ICC Master Code Professional and CBO
- Taught electrical, solar PV, and ESS classes for over 13 years
- Performed well over ten-thousand electrical, solar PV, and ESS plan reviews
- Serve on *NEC* CMP 10 representing IAEI
- Currently serve as a Technical Committee (TC) Member for the following UL standards:
  - UL 61730 (previously 1703) – Flat-Plate PV Modules and Panels
  - UL 1741 - Inverters, Converters, Controllers, and Int. equip…
  - UL 2703 – PV Mounting Systems/Clamps/Gnd. Lugs
  - UL 6703 – Connectors for Use in PV Systems
  - UL 9540 - Energy Storage Systems and Equipment

2

Course Objective/Intent

- The objective of this presentation is to explain the core *NEC/IRC* requirements that govern solar photovoltaic (PV) systems and explain the inspection and plan review processes for them. This presentation is based on the **2020/2023 *NEC* and 2021 *IRC/IFC***.
- The intent of this information is to be <u>used as a guide only</u>. This presentation is not intended to indicate any change in any code or local requirements by inference or omission. All diagrams are for <u>illustration purposes only and actual wiring and installation may vary</u>. This presentation is not intended to indicate if one piece or particular brand of equipment is better than another. Also, efficiency and ideal design considerations are not addressed herein. All applicable codes, standards, and manufacturer requirements must always be followed when designing, installing, and inspecting any electrical system, including solar PV and/or battery/energy storage systems.

3

Outline

1. **PV Modules and Module Interconnections**
2. **Inverters**
3. **Rapid Shutdown**
4. **Micro Inverters VS String Inverters**
5. ***IRC* Roof Access Requirements**
6. **Wiring Methods**
7. **Grounding and Bonding**
8. **Point of Interconnection Requirements**
9. **Example Plan Reviews of PV Systems**
10. **Solar PV Inspections:**
    1. **Roof-Mounted Systems**
    2. **Ground-Mounted Systems**
    3. **General Equipment & Wiring Requirements**
    4. **Solar PV Signage**

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PV Modules (solar panels)

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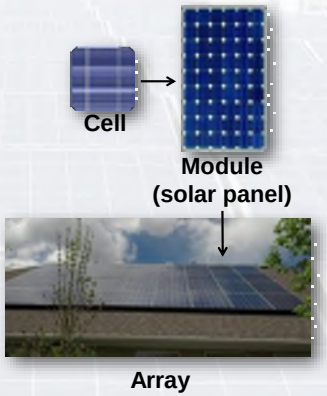
PV Modules

- PV cells make up a PV module (solar panel).
- All modules together in a system make up the array.



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Module Listing

- All photovoltaic modules must be listed as meeting UL UL 61730 (1703).
- *NEC* 690.4(B)

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PV Module Interconnections

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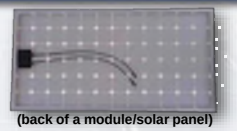
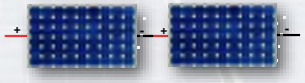
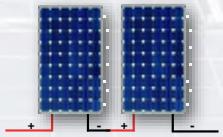
Concept of Series-Connections

- A circuit with multiple modules that are connected in series is referred to by the *NEC* as a "PV Source Circuit," but is often called a string of modules by the PV industry (PV string circuit).







Series connected modules

Note: these diagrams are very basic in order to explain the concept of solar panels connected in series. Most modern-day systems are required to also include rapid shutdown components (such components are not shown here).

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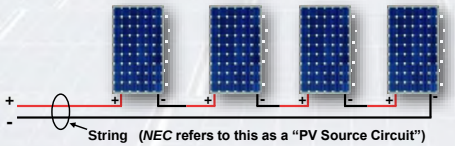
Series vs. Parallel

Series connected modules (solar panels):

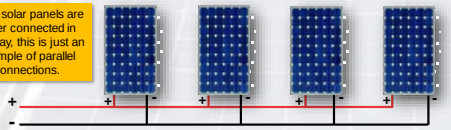
Volts from each module add together but amps stay the same:



Parallel connected modules:

Amps from each module add together but voltage stays the same.

Note: solar panels are never connected in this way, this is just an example of parallel connections.



Note: these diagrams are very basic in order to explain the concept of series versus parallel connections. Most modern-day systems are required to also include rapid shutdown components (such components are not shown here).

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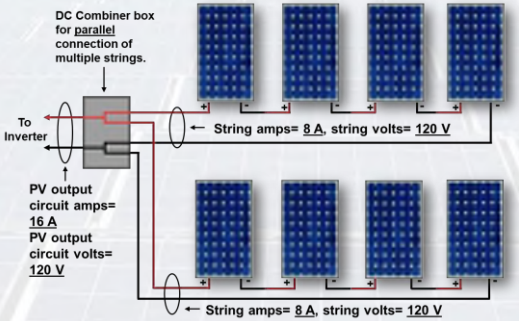
Example of how series and parallel connections affect a system

If each module (solar panel) produced 8 amps and 30 volts…



Note: these diagrams are very basic in order to explain the concept of series versus parallel connections. Most modern-day systems are required to also include rapid shutdown components (such components are not shown here).

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Inverters

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12

Inverters

- Inverters are required for PV systems in order to convert DC power into AC power.
- In most cases, inverter's AC output voltage for residential use is 240V single phase.

Solaredge® String Inverter

SMA® SunnyBoy™ String Inverter

Enphase® IQ7+™ Micro inverter

AP Systems® YC600 Micro inverter

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Inverters

- For commercial use, inverter's AC output voltage can be 208V, 240V, 277V, or 480 volts for 3 phase systems (depending on the model).

SolarEdge® SE66.6kUS

SMA® Tripower Core1-US

Advanced Energy®100kw inverter

Solectria® 60-95 kw inverter

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14

Utility Interactive Inverters

- Any PV Inverters (commercial or residential) that are interconnected with the electric utility grid must meet UL 1741 and be listed as "utility interactive" having anti-islanding protection, *NEC* 705.40.

Solaredge® String Inverter

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Rapid Shutdown

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16

Rapid Shutdown

690.12(B) Controlled Limits:

- The use of the term **array boundary** in this section is defined as **(1 ft) from the array in all directions (and 3' into the attic)**. Controlled conductors outside the array boundary shall comply with *NEC* 690.12(B)(1) and inside the array boundary shall comply with 690.12(B)(2).

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Rapid Shutdown

- **(B)(1) Outside the Array Boundary.** "Controlled conductors located outside the boundary or more than **(3 ft)** from the point of entry inside a building shall be limited to not more than **30 volts within 30 seconds** of rapid shutdown initiation. Voltage shall be measured between any two conductors and between any conductor and ground."

18

Rapid Shutdown

690.12(B)(2) Inside the Array Boundary:

- The PV system must comply with *one* of the following:
  - (1) "A PV hazard control system listed for the purpose **(per UL 3741)** shall be installed in accordance with the instructions included with the listing or field labeling. Where a hazard control system requires initiation to transition to a controlled state, the rapid shutdown initiation device required in 690.12(C) shall perform this initiation."
  - (2) "Controlled conductors located **inside the boundary** or not more than (3 ft) from the point of penetration of the surface of the building shall be limited to not more than **80 volts within 30 seconds** of rapid shutdown initiation. Voltage shall be measured between any two conductors and between any conductor and ground."
  - ~~(3) "PV arrays shall have no exposed wiring methods, no exposed conductive parts, and be installed more than 2.5 m (8 ft) from exposed grounded conductive parts or ground shall not be required to comply with 690.12(B)(2)."~~

NFPE 70, National Electrical Code

19

Rapid Shutdown Initiation Device

***NEC* 690.12(C) Initiation Device:**

- For a one-family and two-family dwelling, the initiation device must be located at a **readily accessible** location on the outside of the building.
- The rapid shutdown initiation device(s) shall consist of at least one of the following:
  - (1) Service disconnecting means.
  - (2) PV system disconnecting means.
  - (3) Readily accessible switch that plainly indicates whether it is in the "off" or "on" position.

Where multiple PV systems are installed with rapid shutdown functions on a single service, the initiation device(s) shall consist of not more than six switches or six sets of circuit breakers, or a combination of not more than six switches and sets of circuit breakers, mounted in a single enclosure, or in a group of separate enclosures.

20

Rapid Shutdown Initiation Device

Example of an older type of rapid shutdown initiation device – "Birdhouse" solar shut-off device by MidNite Solar

Pushbutton switch

Breaker

The type of rapid shutdown initiation device used will depend on the type of rapid shutdown components of the system.

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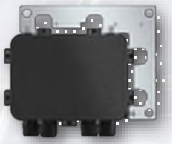
Examples of Rapid Shutdown Equipment

2020 *NEC* 690.12(D) Equipment:

- Equipment that performs the rapid shutdown functions, **other than** initiation devices such as listed disconnect switches, circuit breakers, or control switches, shall be listed for providing rapid shutdown protection.



Tigo® TS4-R-S DC to DC converter

Enphase® micro inverter

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Rapid Shutdown Signage

- **690.12(D) [previously 690.56(C)] Buildings with Rapid Shutdown.** Buildings with PV systems shall have permanent labels as described in 690.12(D)

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Rapid Shutdown Signage

2020 *NEC* Figure 690.56(C), and 2023 *NEC* Figure 690.12(D)

(note: this sign was removed from the 2020 *NEC*)

See also 1205.4 in the 2021 *IFC* for similar requirements.

24

Rapid Shutdown Signage For Buildings with More Than One Rapid Shutdown Type

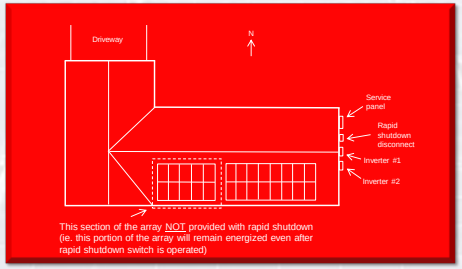
***NEC* 690.12(D)(1) [previously 690.56(C)(1)] Buildings with More Than One Rapid Shutdown Type:**

- For buildings that have PV systems with more than one type of rapid shutdown, **or** a PV system with a rapid shutdown type and a PV system with no rapid shutdown, a detailed plan view diagram of the roof shall be provided showing each different PV system and a dotted line around areas that remain energized after the rapid shutdown switch is operated.

25

Rapid Shutdown Signage For Buildings with More Than One Rapid Shutdown Type

Example of a plaque showing which portion(s) of the PV system are equipped with rapid shutdown and which are not:



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Rapid Shutdown Switch Signage

- ***NEC* 690.56(C)(2) Rapid Shutdown Switch.** A rapid shutdown switch shall have a label located on or no more than (3 ft) from the switch that includes the following wording: **"RAPID SHUTDOWN SWITCH FOR SOLAR PV SYSTEM"**
- The label shall be reflective, with all letters capitalized and having a minimum height of 9.5 mm (3⁄8 in.), in white on red background.

Rapid Shutdown Switch
For Solar PV System

Sign located next to the rapid shutdown disconnect (and must be reflective)

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Micro Inverter Systems VS String Inverter Systems

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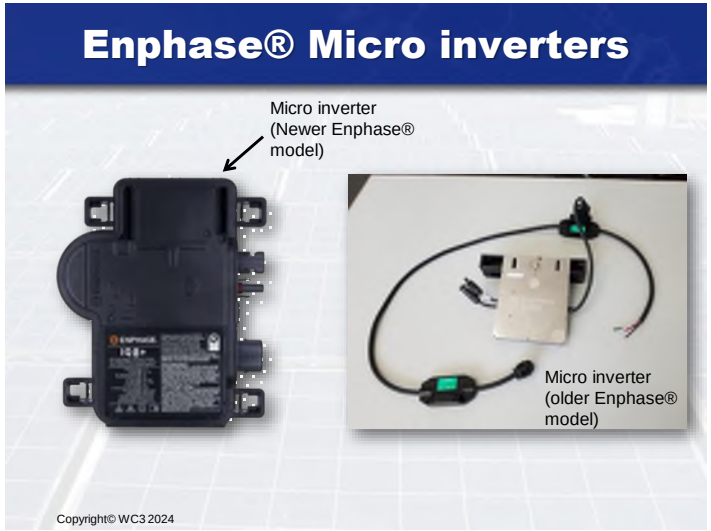
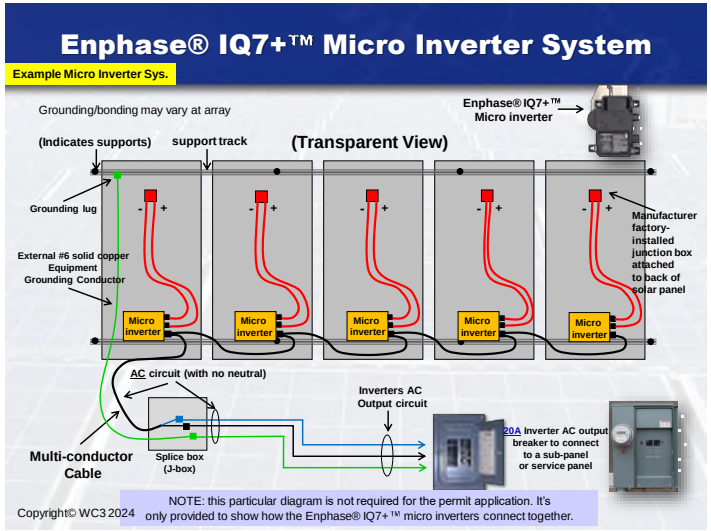

Enphase® Micro inverters
Micro inverter (Newer Enphase® model)
Micro inverter (older Enphase® model)
Copyright© WC3 2024

29


Enphase® IQ7+™ Micro Inverter System
Example Micro Inverter Sys.
Grounding/bonding may vary at array
Enphase® IQ7+™ Micro inverter
(Indicates supports)
support track
(Transparent View)
Grounding lug
Manufacturer factory-installed junction box attached to back of solar panel
External #6 solid copper Equipment Grounding Conductor
Micro inverter
AC circuit (with no neutral)
Inverters AC Output circuit
Multi-conductor Cable
Splice box (J-box)
20A Inverter AC output breaker to connect to a sub-panel or service panel
NOTE: this particular diagram is not required for the permit application. It's only provided to show how the Enphase® IQ7+™ micro inverters connect together.
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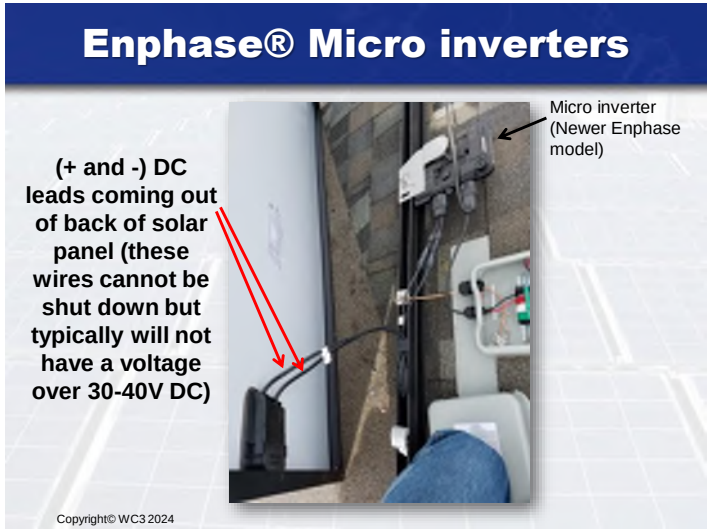
30


Enphase® Micro inverters
(+ and -) DC leads coming out of back of solar panel (these wires cannot be shut down but typically will not have a voltage over 30-40V DC)
Micro inverter (Newer Enphase model)
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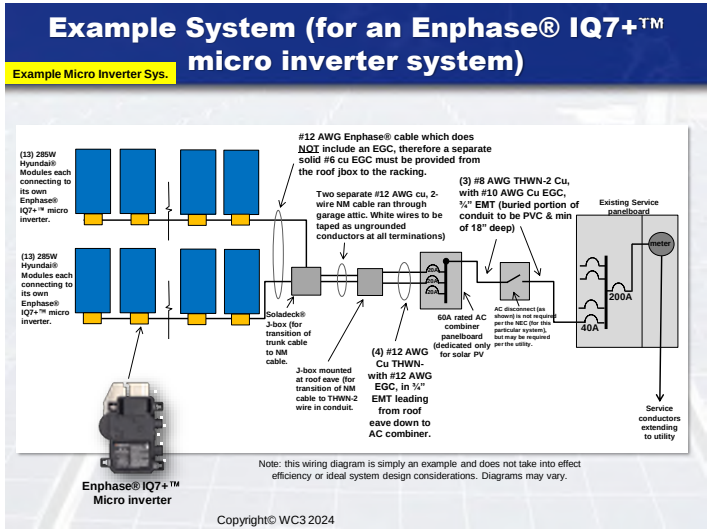
31


Example System (for an Enphase® IQ7+™ micro inverter system)
Example Micro Inverter Sys.
(13) 285W Hyundai® Modules each connecting to its own Enphase® IQ7+™ micro inverter.
(13) 285W Hyundai® Modules each connecting to its own Enphase® IQ7+™ micro inverter.
#12 AWG Enphase® cable which does NOT include an EGC, therefore a separate solid #6 cu EGC must be provided from the roof jbox to the racking.
Two separate #12 AWG cu, 2-wire NM cable ran through garage attic. White wires to be taped as ungrounded conductors at all terminations)
(3) #8 AWG THWN-2 Cu, with #10 AWG Cu EGC, ¾" EMT (buried portion of conduit to be PVC & min of 18" deep)
Existing Service panelboard
meter
200A
40A
Soladeck® J-box (for transition of trunk cable to NM cable.
J-box mounted at roof eave (for transition of NM cable to THWN-2 wire in conduit.
(4) #12 AWG Cu THWN- with #12 AWG EGC, in ¾" EMT leading from roof eave down to AC combiner.
60A rated AC combiner panelboard (dedicated only for solar PV
AC disconnect (as shown) is not required per the NEC (for this particular system), but may be required per the utility.
Service conductors extending to utility
Enphase® IQ7+™ Micro inverter
Note: this wiring diagram is simply an example and does not take into effect efficiency or ideal system design considerations. Diagrams may vary.
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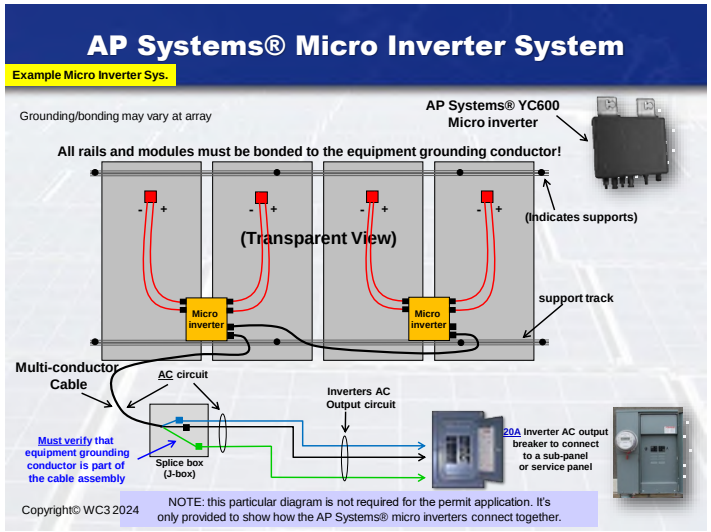
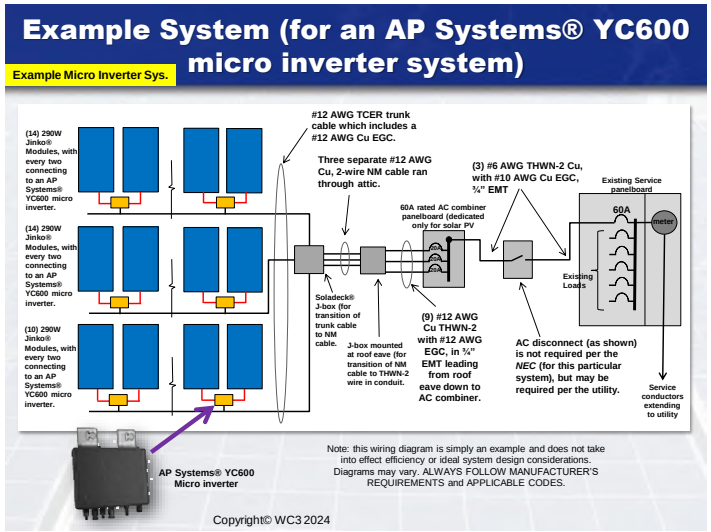
32


AP Systems® Micro Inverter System
Example Micro Inverter Sys.
Grounding/bonding may vary at array
AP Systems® YC600 Micro inverter
All rails and modules must be bonded to the equipment grounding conductor!
(Indicates supports)
(Transparent View)
Micro inverter
Micro inverter
support track
Multi-conductor Cable
AC circuit
Inverters AC Output circuit
Must verify that equipment grounding conductor is part of the cable assembly
Splice box (J-box)
20A Inverter AC output breaker to connect to a sub-panel or service panel
Copyright© WC3 2024
NOTE: this particular diagram is not required for the permit application. It's only provided to show how the AP Systems® micro inverters connect together.

33


Example System (for an AP Systems® YC600 micro inverter system)
Example Micro Inverter Sys.
(14) 290W Jinko® Modules, with every two connecting to an AP Systems® YC600 micro inverter.
(14) 290W Jinko® Modules, with every two connecting to an AP Systems® YC600 micro inverter.
(10) 290W Jinko® Modules, with every two connecting to an AP Systems® YC600 micro inverter.
#12 AWG TCER trunk cable which includes a #12 AWG Cu EGC.
Three separate #12 AWG Cu, 2-wire NM cable ran through attic.
(3) #6 AWG THWN-2 Cu, with #10 AWG Cu EGC, ¾" EMT
Existing Service panelboard
60A
meter
60A rated AC combiner panelboard (dedicated only for solar PV
Existing Loads
Soladeck® J-box (for transition of trunk cable to NM cable.
J-box mounted at roof eave (for transition of NM cable to THWN-2 wire in conduit.
(9) #12 AWG Cu THWN-2 with #12 AWG EGC, in ¾" EMT leading from roof eave down to AC combiner.
AC disconnect (as shown) is not required per the NEC (for this particular system), but may be required per the utility.
Service conductors extending to utility
AP Systems® YC600 Micro inverter
Note: this wiring diagram is simply an example and does not take into effect efficiency or ideal system design considerations. Diagrams may vary. ALWAYS FOLLOW MANUFACTURER'S REQUIREMENTS and APPLICABLE CODES.
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String inverters
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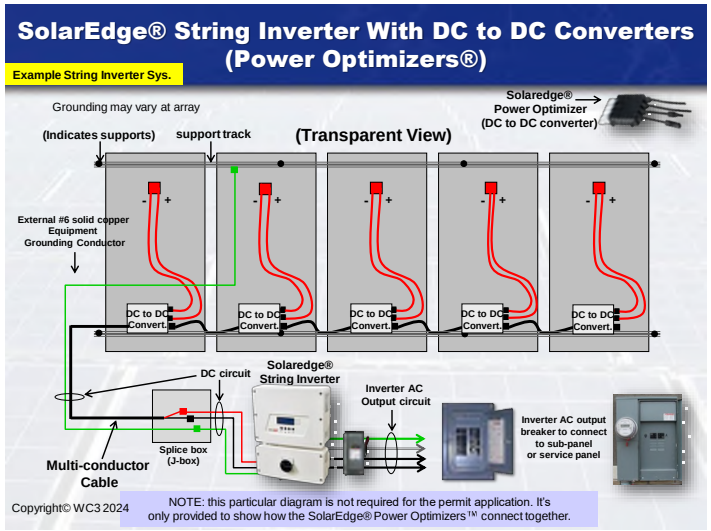
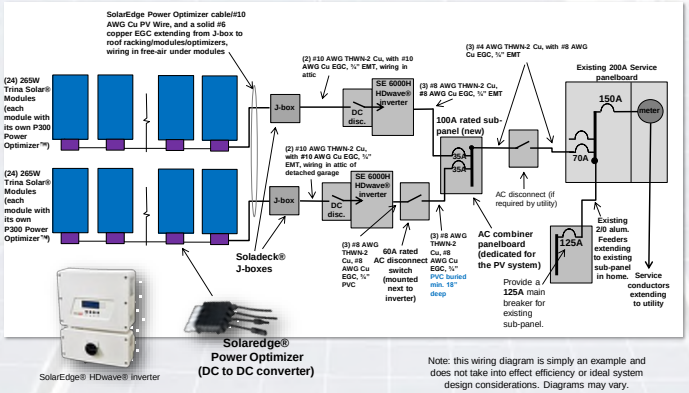

SolarEdge® String Inverter With DC to DC Converters (Power Optimizers®)
Example String Inverter Sys.
Grounding may vary at array
Solaredge® Power Optimizer (DC to DC converter)
(Indicates supports)
support track
(Transparent View)
External #6 solid copper Equipment Grounding Conductor
DC to DC Convert.
DC circuit
Solaredge® String Inverter
Inverter AC Output circuit
Splice box (J-box)
Multi-conductor Cable
Inverter AC output breaker to connect to sub-panel or service panel
Copyright© WC3 2024
NOTE: this particular diagram is not required for the permit application. It's only provided to show how the SolarEdge® Power Optimizers™ connect together.

36

A SolarEdge® system (with two HDwave® SolarEdge® inverters)

Example String Inverter Sys.



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SolarEdge® String inverters

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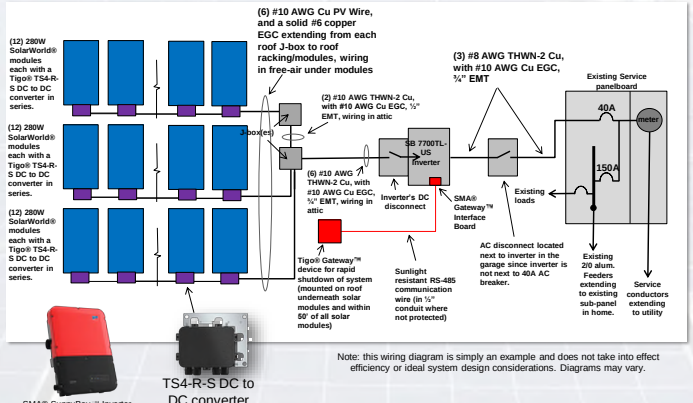
Example Single-Line Diagram (for an SMA® inverter with full rapid shutdown equipment)



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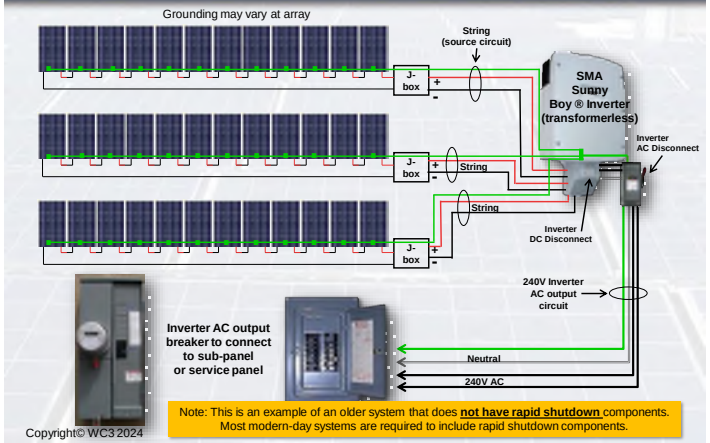
39

Example System – Older String Inverter

Example String Inverter Sys.



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Carports/Shade Structures



Per the 2023 *NEC*, Section 690.12, non-enclosed detached structures do <u>NOT</u> require rapid shutdown functionality.

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DC Ground Fault Protection (GFPD)

- PV systems operating at over 30V DC or 8 amps are required to have DC ground fault protection, *NEC* 690.41(B).
- Most PV inverters incorporate a DC GFPD (always verify with the inverter manufacturer!).


Solaredge®


SMA® SunnyBoy™ Inverter

Note: even micro inverters are required to have listed DC ground fault protection.

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Tesla® Shingles
(often considered as BIPV)

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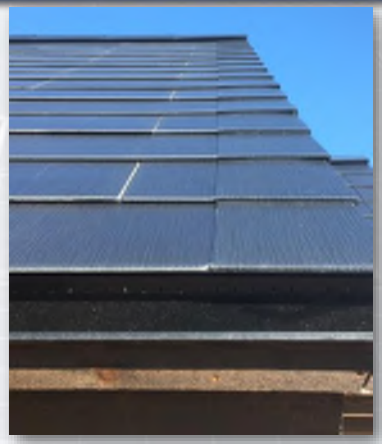
Tesla® Shingles

Tesla® shingle systems are required to have what Tesla calls middle circuit interrupters (MCIs) throughout the solar array in order for the system to be rapid shutdown compliant.



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IRC Roof Access Provisions (per the 2021 *IRC*)

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Roof Access For Venting

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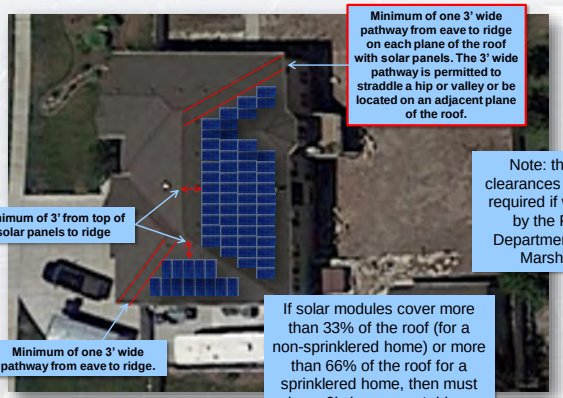
46

Roof Fire Access (2021 *IRC* Section R324.6)



Note: these clearances are not required if waived by the Fire Department/Fire Marshall

If solar modules cover more than 33% of the roof (for a non-sprinklered home) or more than 66% of the roof for a sprinklered home, then must have 3' clearance at ridge.

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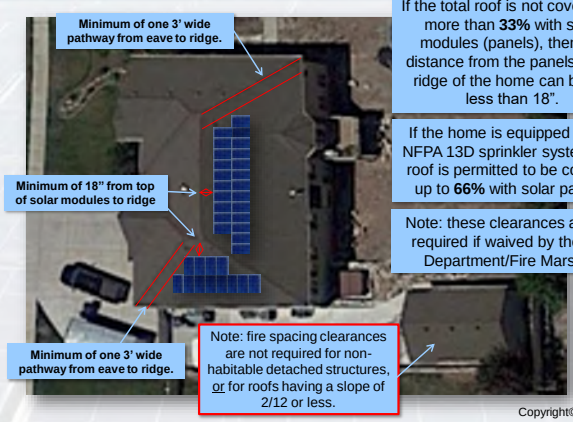
Roof Fire Access (2021 *IRC* Section R324.6)



If the total roof is not covered by more than **33%** with solar modules (panels), then the distance from the panels to the ridge of the home can be not less than 18".

If the home is equipped with a NFPA 13D sprinkler system, the roof is permitted to be covered up to **66%** with solar panels.

Note: these clearances are not required if waived by the Fire Department/Fire Marshall

Note: fire spacing clearances are not required for non-habitable detached structures, <u>or</u> for roofs having a slope of 2/12 or less.

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Access to Egress Openings (IRC R324.6.3)

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Wiring Methods

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50

Wire Types

- For PV DC circuits exposed outside, listed "PV wire" or USE-2 and RHW-2 wire must be used (and marked as sunlight resistant), *NEC* 690.31(C)(1).
- Cables to be secured every 24" using listed ties, straps, hangers, etc., where exposed.
- Wiring is also required to be protected from physical damage per *NEC* 300.4

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Installation Errors

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690.31(C)(3) Multiconductor Cable

Multiconductor Cables:

- Where part of a listed PV assembly, multiconductor jacketed cables shall be installed in accordance with the included instructions.
- Where not part of a listed assembly, or where not otherwise covered in the *NEC*, multiconductor jacketed cables, including DG cable, shall be installed in accordance with the product listing and shall be permitted in PV systems and must meet the requirements of items 690.31(C)(3)(1) and (C)(3)(2).

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53

Wire Protection
(where DC conductors are readily accessible)

***NEC* 690.31(A):**

- Where PV source and output circuits operating at voltages greater than 30 volts are installed in readily accessible locations, circuit conductors shall be **guarded or installed in Type MC cable or in raceway**.

"Guarded circuit conductors?

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Wire Protection
(where DC conductors are readily accessible)

Fence around array could potentially be considered as "guarding" the wiring at the array, if approved by AHJ.

Wires located in readily accessible locations shall be installed in raceways, MC cable, or be guarded, *NEC* 690.31(A).

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Accessible DC Wiring?

Ground-mount solar array – DC wires guarded?

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Wiring Methods

690.31(D) – DC Circuits in/on Buildings:

- Whenever dc circuits for PV systems operate over 30V or 8 amps and are inside a building, such circuits must be in metal raceways, MC cable, or metal enclosures.
  - New exception: Non-metallic enclosures, raceways, or cables that are part of a listed PV hazard control system are permitted at the point of penetration of the building to the PV hazard control actuator.

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Wiring Methods

690.31(D)(2) – Markings/Labels:

- There must be provided labels on the exterior of all exposed raceways, enclosures, boxes, and conduit bodies. The wording of the labels must state either of the following: "PHOTOVOLTAIC POWER SOURCE" or "SOLAR PV DC CIRCUIT."

PHOTOVOLTAIC POWER SOURCE

Or

SOLAR PV DC CIRCUIT

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Grounding and Bonding

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Grounding and Bonding of Equipment

Equipment to be grounded:

- ***NEC* 690.43:** The metal parts of all modules, support rails, elect. boxes, and other equipment associated with the PV system must be bonded together and connected to an equipment grounding conductor.
- **690.43(A):** Devices and systems used for mounting PV modules that are also used for bonding module frames shall be listed, labeled, and identified for bonding PV modules. Devices that mount adjacent PV modules shall be permitted to bond adjacent PV modules.

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Racking With Integrated Bonding

SnapNrack® racking with integrated bonding

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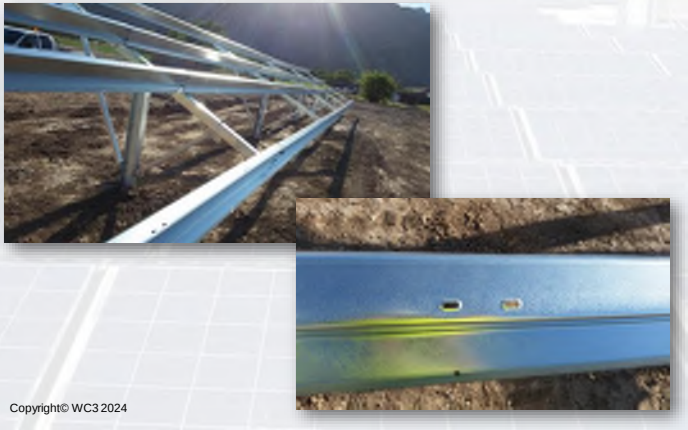
Ground-Mounted System Racking With Integrated Bonding



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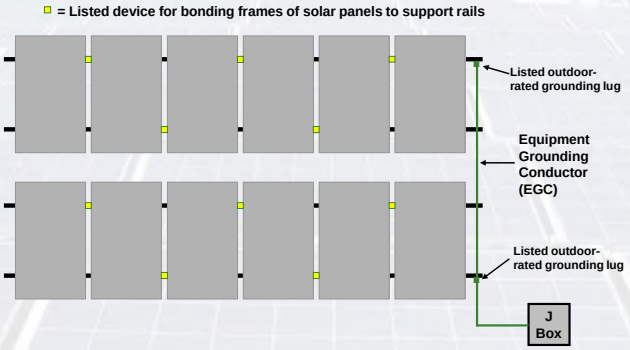
62

Bonding Metal Parts To The Equipment Grounding Conductor (EGC)



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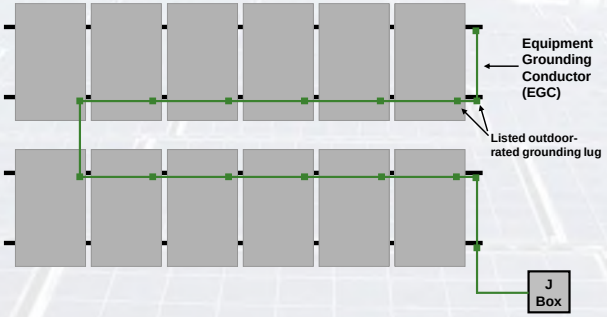
Bonding Supports And Modules



If listed bonding devices are not used, each module and each rail must be individually connected to the equipment grounding conductor.

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Grounding and Bonding

690.45 – Size of EGCs:

- 690.45 of the 2020 *NEC* notes that it is <u>not</u> required to increase the size of the equipment grounding conductor (EGC) to address voltage drop considerations.

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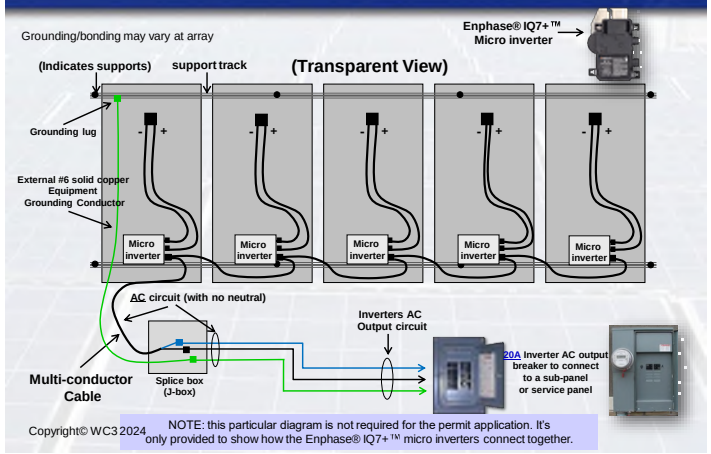
Grounding and Bonding

2020 *NEC* 690.47(A) - Grounding Electrode System:

- A building or structure that supports a PV system must have a grounding electrode system (per Part III of *NEC* Article 250).
- For connection of the PV system to the grounding electrode system, either of the applicable following methods must be used:
  - PV systems that are <u>NOT</u> solidly grounded (<u>such as functionally grounded systems</u>) the equipment grounding conductor (EGC) of inverter's ac output circuit is permitted to be the only connection to ground for the PV system when such equipment ground wire is connected to a distribution system that is already connected to a grounding electrode system.
  - The second option applies to solidly grounded PV systems (see 690.47(A)(2). These systems are very rare.

66

Enphase® IQ7+™ Micro Inverter System



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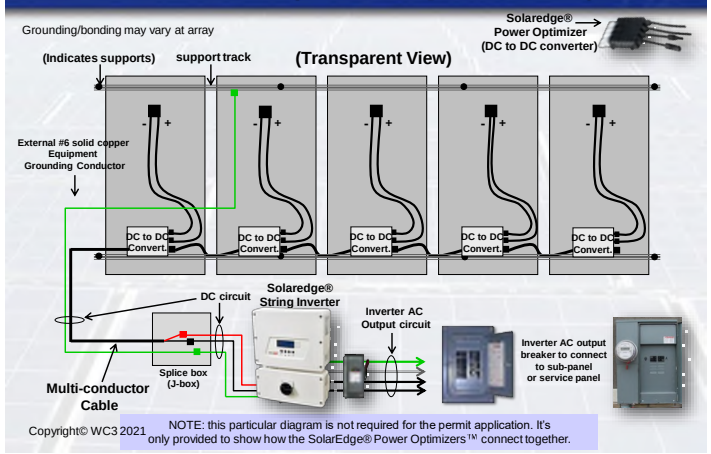
Solaredge® String Inverter With DC to DC Converters (Power Optimizers®)



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Point of Interconnection Requirements (Article 705)

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Splices and Taps

230.46 – Splices and Taps

- Effective January 1, 2023 any pressure connectors and devices for splicing or taps onto service conductors must be marked "suitable for use on the line side of the service equipment," or equivalent wording.

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Multiple Sources of Power

705.10 – Identification of Power Sources:

- A permanent plaque or directory is required to be installed at each service equipment location (or other readily visible location). Such must denote the location of each power source disconnecting means for the building or structure and be grouped with any other plaques or directories.
- Such plaque or directory must be marked with the words "CAUTION: MULTIPLE SOURCES OF POWER."

71

Point Of Interconnection

Connecting The PV System To The Bld's Elect. System:

- There are 2 general places a PV system can *potentially* connect to a building's electrical system:
  - On the supply side (line side) of the building's main service disconnect.
  - On the load side of the building's main service disconnect.

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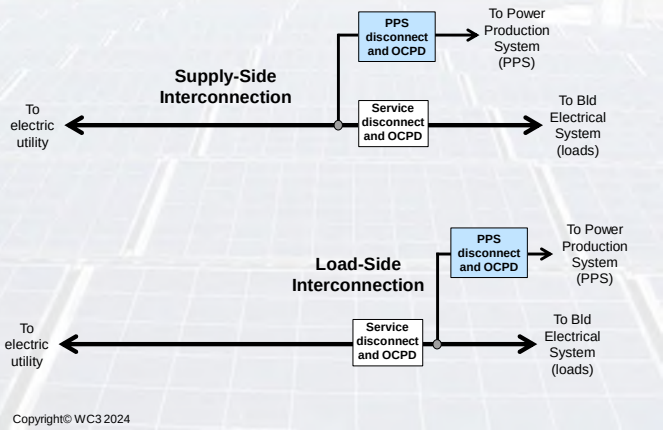
Supply (line) Connections Vs Load Connections



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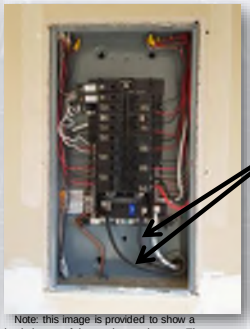
Supply (Line) Side Connection

***NEC* 705.11:**

- An electric power production source is permitted to be connected on the supply side of a service disconnecting means per 230.82(6). Such interconnection must also comply with the other requirements of 705.11.
  - Note: 230.82(6) specifies that solar PV systems are permitted to be on the supply side of the service disconnecting means if the PV system disconnecting means is listed as suitable for use as service equipment.

74

Supply-Side Interconnection



Note: this image is provided to show a basic layout of the service equipment. The intent is NOT to point out every code violation of the install.

A power production system connection to these service-entrance conductors is ONE example of a supply-side interconnection.

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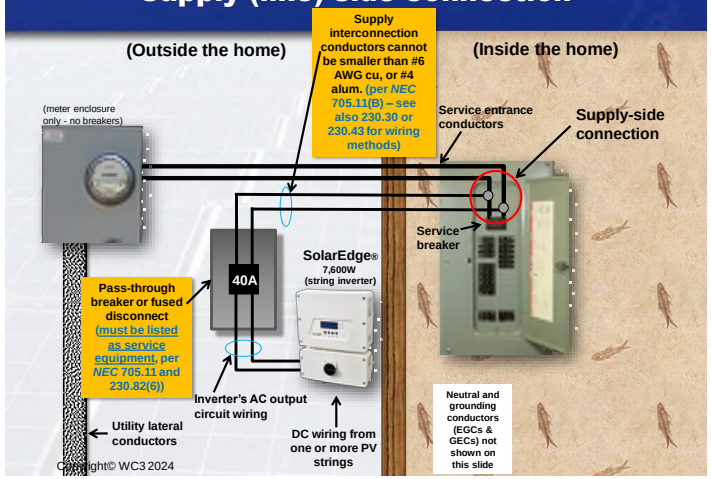
Supply (line) side connection



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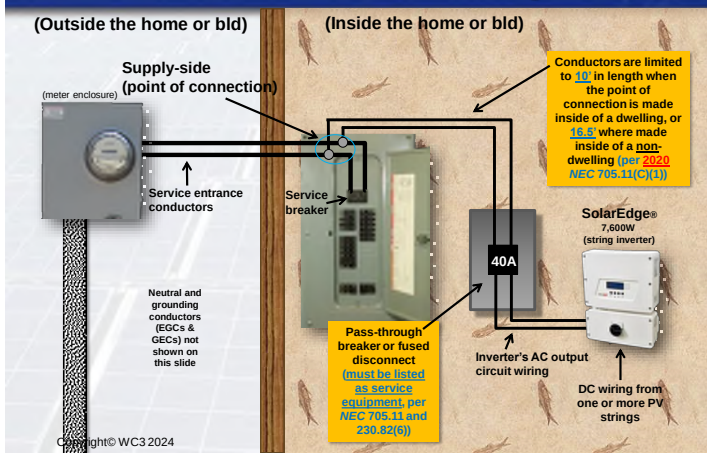
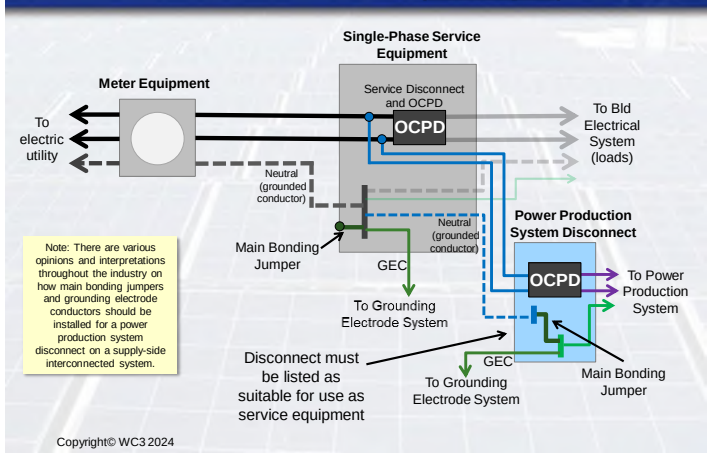
Supply (line) side connection (2020 *NEC*) – Made Inside of a Building



77

Section 250.25 of the 2020 & 2023 *NEC* (example)



78

Supply (line) side connection continued…

- This particular Square D service meter-main combo panelboard allows for supply-side interconnections to be made to the busbars located above the main breaker (see Square D model SC2040M200PS)

Note: this image is provided to show a basic layout of the service equipment. The intent is NOT to point out every code violation of the install.

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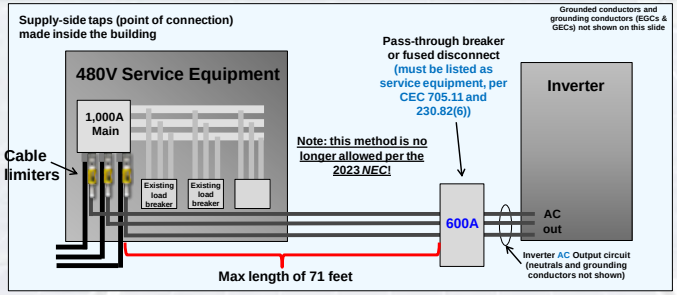
Supply (line) side connection (2020 *NEC*) – Made Inside of a Building



For non-dwellings, the overcurrent protection device can be located within 71 feet (maximum conductor length) as long as cable limiters are provided for each ungrounded conductor. The cable limiters would need to be within 16.5 feet of the point of connection (maximum conductor length).

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Supply (line) side connection continued…

Cooper Bussman cable limiter

Ferraz Shawmut cable limiters

Examples of cable limiters

81

Supply (Line) side connection continued…

What about supply-side connections made with a breaker?

Note: these images are provided to show a basic layout of the service equipment. The intent is NOT to point out every code violation of the install.

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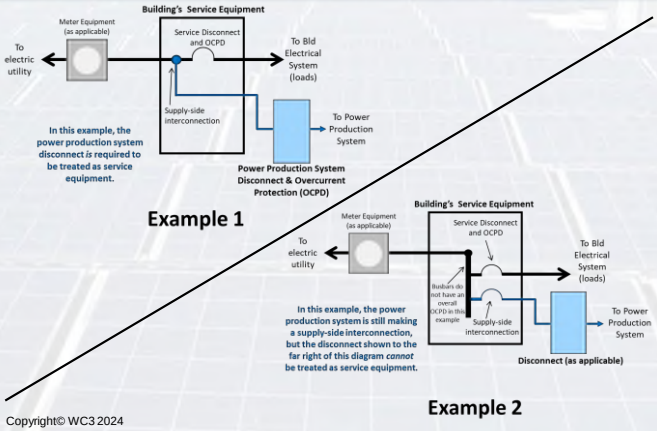
Supply (Line) side connection continued…



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When Overcurrent Protection is Provided at the Supply End of the Conductors

In this scenario any disconnect or panelboard on the *load* side of the service breaker is NOT treated as service equipment, NOR can there be any neutral-to-ground bonding connections in it/them.

(disconnect switch, panelboard, etc.) → To Power Production System

NOT SERVICE EQUIPMENT

Note: this image is provided to show a basic layout of the service equipment. The intent is NOT to point out every code violation of the install.

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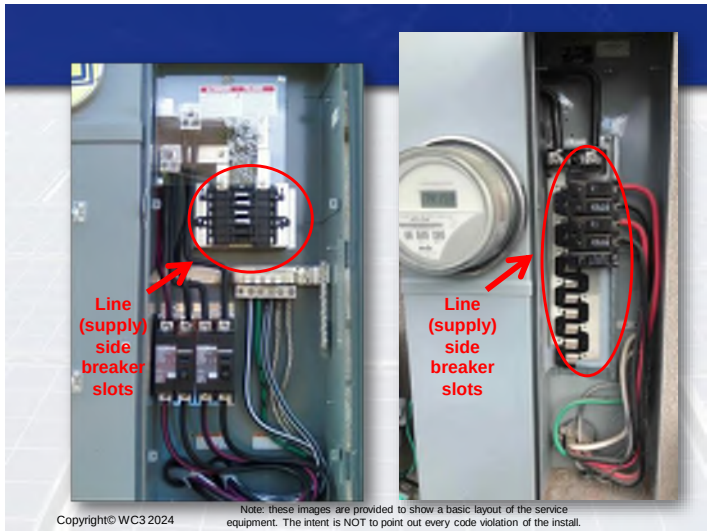
Line (supply) side breaker slots
Line (supply) side breaker slots
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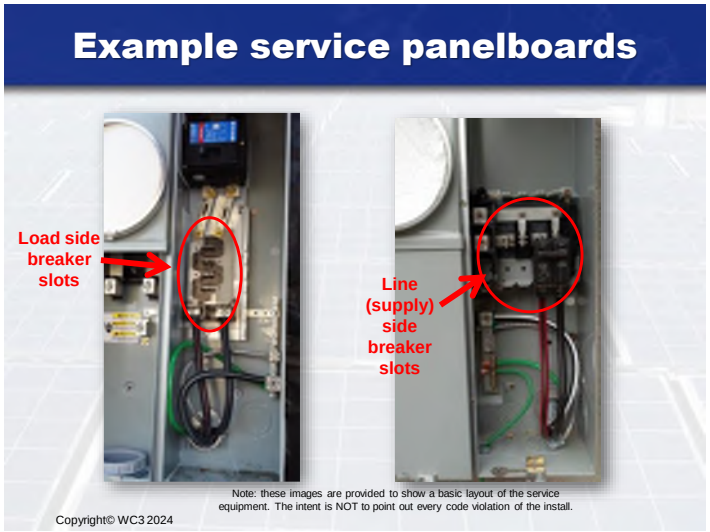
Note: these images are provided to show a basic layout of the service equipment. The intent is NOT to point out every code violation of the install.

85


Example service panelboards
Load side breaker slots
Line (supply) side breaker slots
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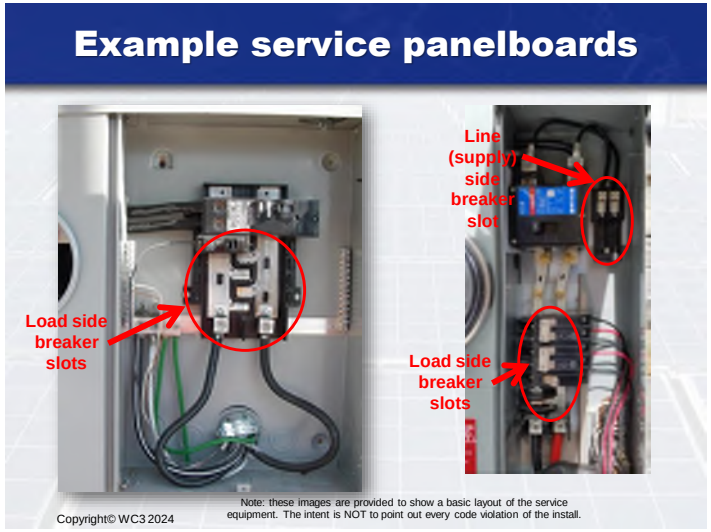
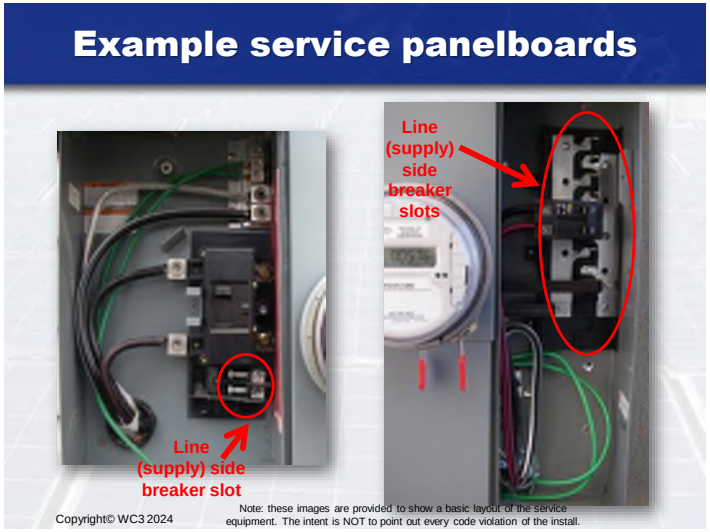
Note: these images are provided to show a basic layout of the service equipment. The intent is NOT to point out every code violation of the install.

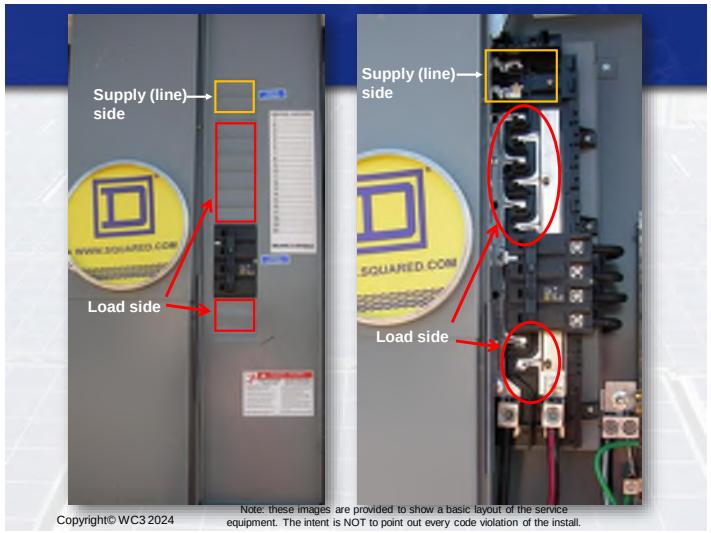
86


Example service panelboards
Line (supply) side breaker slot
Load side breaker slots
Load side breaker slots
Copyright© WC3 2024
Note: these images are provided to show a basic layout of the service equipment. The intent is NOT to point out every code violation of the install.

87

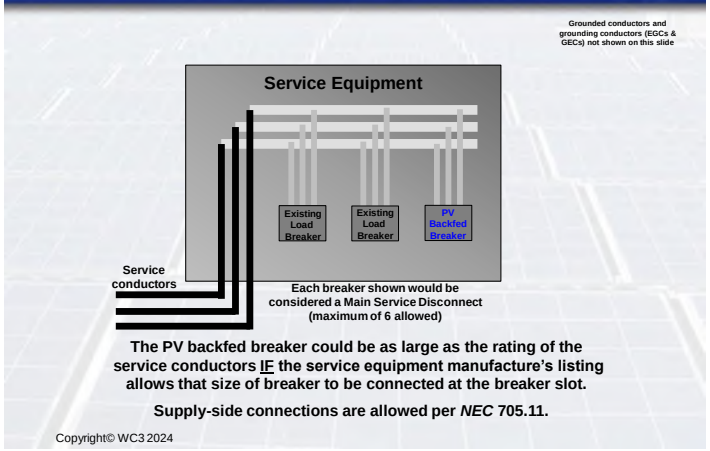

Example service panelboards
Line (supply) side breaker slots
Line (supply) side breaker slot
Copyright© WC3 2024
Note: these images are provided to show a basic layout of the service equipment. The intent is NOT to point out every code violation of the install.

88



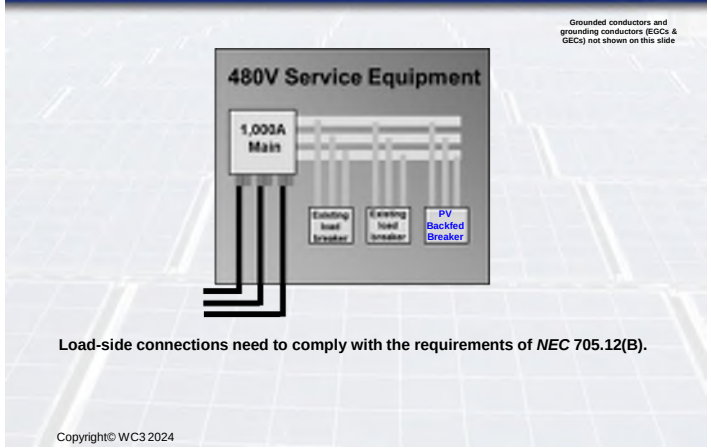
89

Supply (line) Side Of Main Service Disconnect (for large service equipment)



90

Load-Side Connections



91

Load Side Connections – 705.12

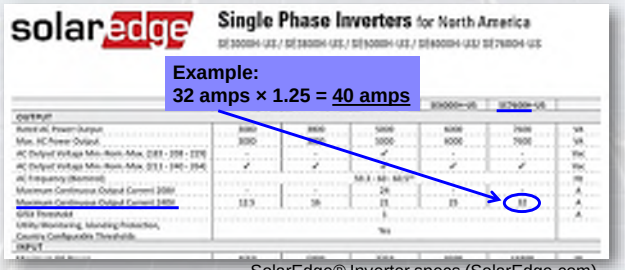
- Load side connections occur on the building's side of the main electrical service disconnect(s).
- The requirements of *NEC* 705.12 in the 2023 *NEC* are similar to those shown in 705.12 of the 2020 *NEC*, with a few minor changes.
- **For the purposes of this presentation, the methods of load side interconnections per the 2023 *NEC* will be shown on the following slides.**

92

705.12(A) or (B) - Bus or Conductor Ampacity Rating

Bus or Conductor Calculations:

- 125% of the inverter(s) AC (or "power source") output current is to be used when determining the ampacity calculations of 705.12(B)(1) through (B)(3).



SolarEdge® Inverter specs (SolarEdge.com)

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705.12(A) – Feeders

Feeders

- When an inverter ("power source") connection is made to a feeder, the feeder is required to have an ampacity not less than 125% of the output current (amps) of the inverter(s).
- Per 705.12(A)(2), when the inverter ("power source") AC output connection is made to a feeder at a location **other than** the opposite end of the feeder from the primary source overcurrent device, the portion of feeder on the load side of the inverter ("power source") output connection must be protected by *NEC* 705.12(A)(2)(**a**) or (A)(2)(**b**).

94

705.12(A)(2) (Feeders) continued…

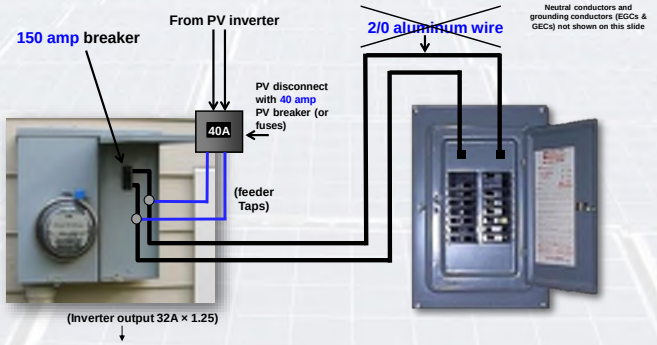
- If the PV connection to a feeder is not at the opposite end of the feeder from the feeder's main breaker (primary overcurrent protection device), the feeder's ampacity on the load side of the PV connection must be as per *NEC* 705.12(A)(2)(**a**) or (A)(2)(**b**):
  - a) The feeder ampacity must not be less than the sum of the primary source OCPD and 125% of the inverter(s) (power source) output current.

    OR
  - b) An overcurrent device on the load side of the inverter (power source) AC output connection must be rated not greater than the ampacity of the feeder.

95

Feeders – Example For Option "a" (*NEC* 705.12(A)(2)(a))

Option "a": The feeder must have an ampacity of the sum of the primary source OCPD and the inverter AC output amps × 1.25:



150A + 40A= 190 amps – 2/0 aluminum is too small!

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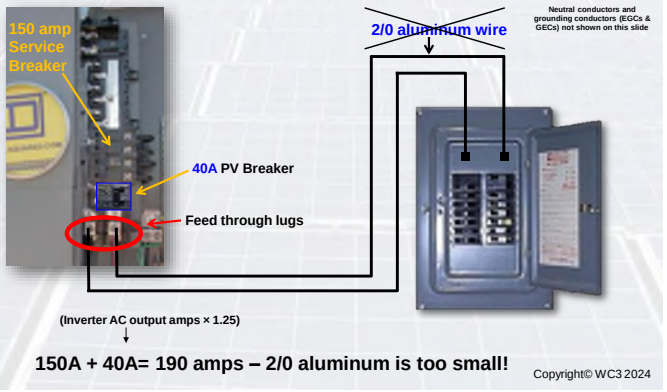
Feeders – Another Example For Option "a" (*NEC* 705.12(A)(2)(a))

Option "a": The feeder wires must have an ampacity of the sum of the primary source OCPD and the inverter AC output amps × 1.25:



150A + 40A= 190 amps – 2/0 aluminum is too small!

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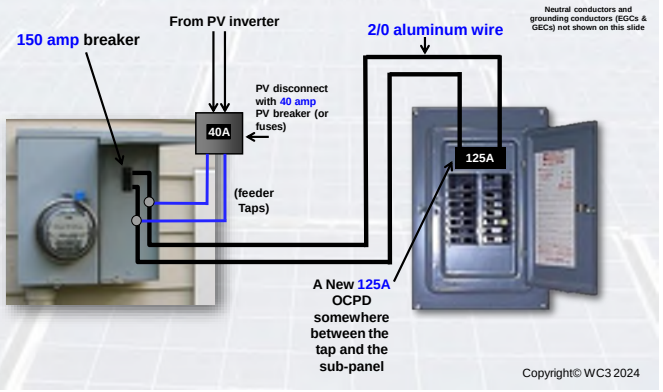
Feeders – Example For Option "b" (*NEC* 705.12(A)(2)(b))

Option "b": An OCPD on the load side of the inverter (power source) connection must be rated not greater than the ampacity of the feeder.



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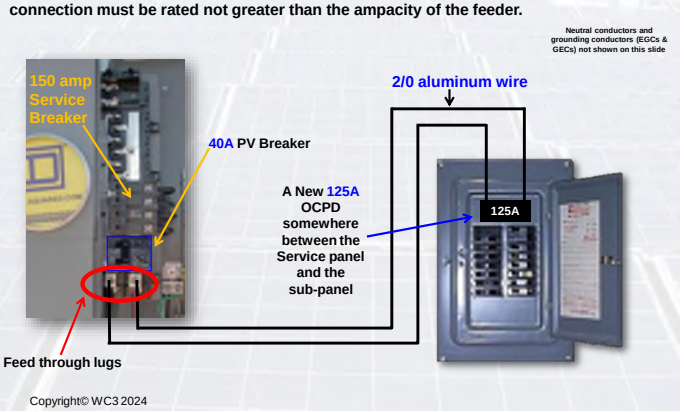
Feeders – Another Example For Option "b" (*NEC* 705.12(A)(2)(b))

Option "b": An OCPD on the load side of the inverter (power source) connection must be rated not greater than the ampacity of the feeder.



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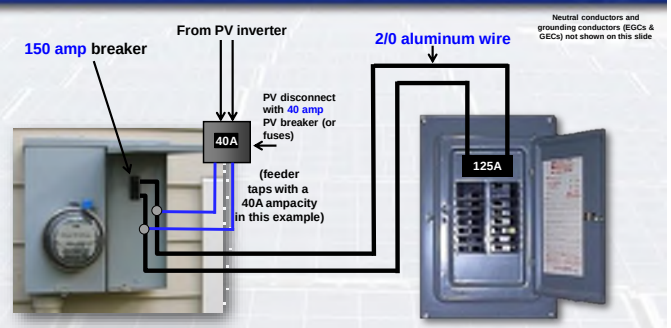
NEC 705.12(A)(3) – Taps

Feeder Taps:

- Where inverter (power source) AC output circuits tap feeder conductors, the **taps** are to be sized based on 125% of the inverter (power source) output circuit current.
- If either 240.21(B)(2) or (B)(4) will be used (<u>for taps over 10 feet and up to 25 feet long</u>), then the ampacity of the taps cannot be less than 1/3 of the sum of the rating of the OCPD that is protecting the feeder conductors plus the rating of the power source OCPD.

100

NEC 705.12(A)(3) – Taps continued…



As long as the feeder taps are <u>not over 10 feet long</u>, per *NEC* 705.12(A)(3) the tap conductors must have an ampacity of 125% of the rated output amps of the inverter (which is 40A for a 32A inverter).

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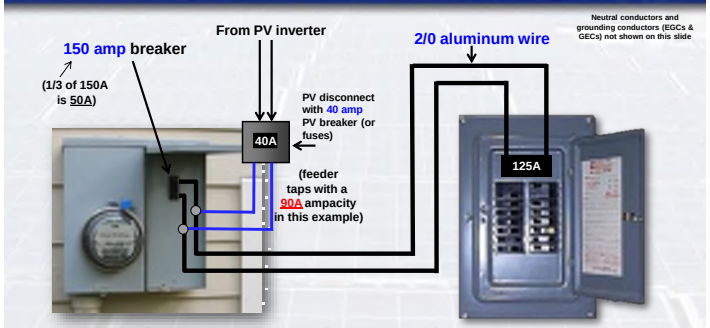
NEC 705.12(A)(3) – Taps OVER 25 Feet Long



IF the feeder taps are <u>longer than 10 feet but not over 25 feet</u>, per *NEC* 705.12(A)(3) the tap conductors must have an ampacity of at least 1/3 of the 150A main breaker plus the rating of the inverter's OCPD (which is 90A for this example).

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NEC 705.12(B) – Busbars

Busbars

- *NEC* 705.12(B)(1) through (B)(6) must be used for determining the minimum ratings of panelboard busbars.

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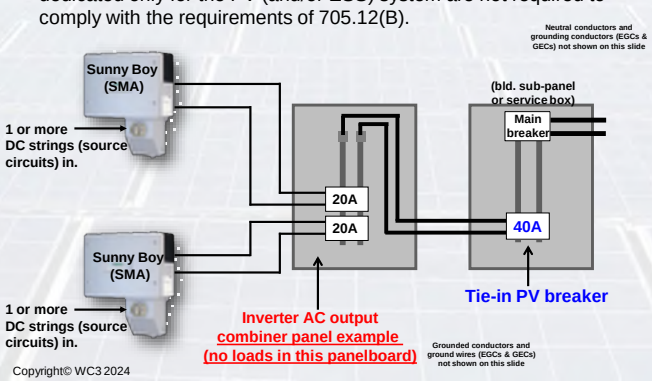
Panelboards with only power source connections (i.e. often called <u>AC combiners</u>)

- It's a common interpretation by AHJs that panelboards which are dedicated only for the PV (and/or ESS) system are not required to comply with the requirements of 705.12(B).



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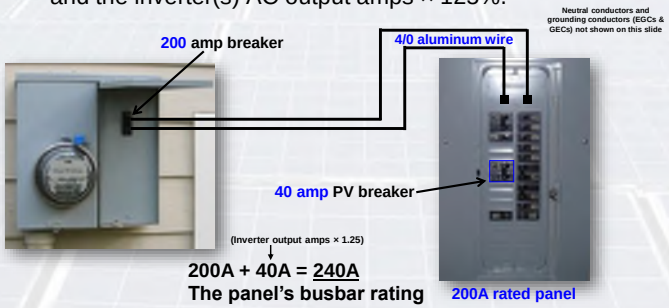
Busbars – Example For Method "1" (*NEC* 705.12(B)(1))

1) The busbars in a panel must be rated for at least the sum of the rating of the OCPD protecting the busbar and the inverter(s) AC output amps × 125%.



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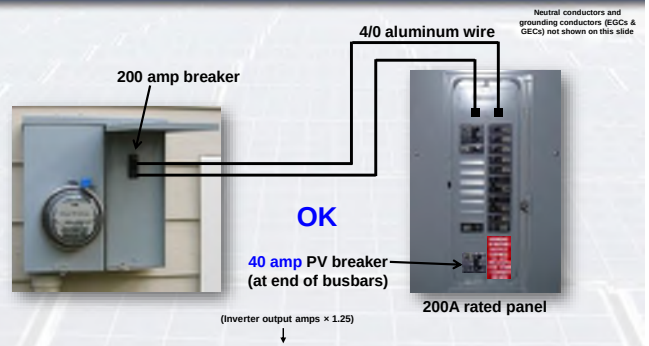
Method "2" (*NEC* 705.12(B)(2))

2) Where two sources, one a utility (primary power source) and the other an inverter (or other power source), are located at opposite ends of a busbar that also has other loads, the sum of the rating of the OCPD protecting the busbar and the inverter(s) (power source) current rating × 125% cannot exceed 120% of the rating of the busbar.

- The busbars must already be sized for the connected loads as per Article 220 in the *NEC*.
- A sign must be provided next to the backfed PV breaker stating: "WARNING: POWER SOURCE OUTPUT - DO NOT RELOCATE THIS OVERCURRENT DEVICE"

106

Example for method "2" (*NEC* 705.12(B)(2))



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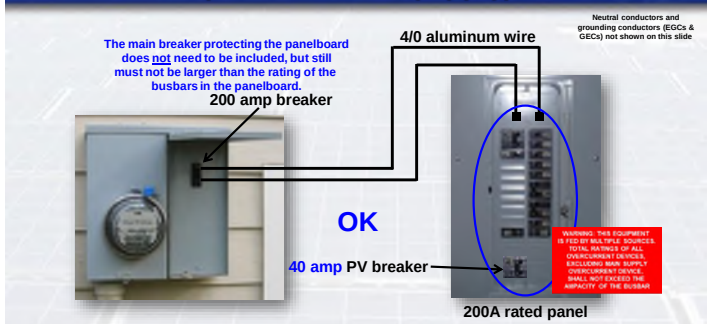
Method "3" (*NEC* 705.12(B)(3))

3) The sum of the ampere ratings of all breakers (OCPDs) on panelboards, including load and supply breakers (but NOT counting the main breaker protecting the panel), must not exceed the rating of the panelboard's busbars.

- The rating of the main breaker protecting the panelboard must not exceed the rating of the busbars.
- Permanent warning label must be applied to the panel (distribution equipment) with the words: "WARNING: EQUIPMENT FED BY MULTIPLE SOURCES. TOTAL RATINGS OF ALL OVERCURRENT DEVICES, EXCLUDING MAIN SUPPLY OVERCURRENT DEVICE, SHALL NOT EXCEED THE AMPACITY OF BUSBAR."

108

Example for method "3" (*NEC* 705.12(B)(3))



The combined ratings of all breakers at the above shown panelboard must not exceed the rating of the panelboard's busbars.

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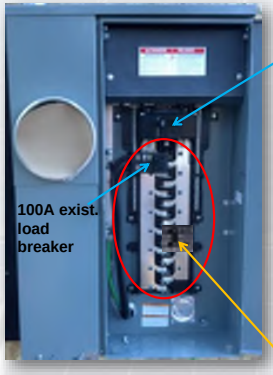
109

Another example for method "3" (*NEC* 705.12(B)(3))

Note: this image is provided to show a basic layout of the service equipment. The intent is NOT to point out every code violation of the install.



200A rated service panelboard with a 200A main service breaker.

The sum of the breakers in this panel (including the solar PV breaker but NOT counting the main 200A service breaker) could not exceed 200A, per *NEC* 705.12(B)(3).

100A exist. load breaker

WARNING: THIS EQUIPMENT IS FED BY MULTIPLE SOURCES. TOTAL RATINGS OF ALL OVERCURRENT DEVICES, EXCLUDING MAIN SUPPLY OVERCURRENT DEVICE, SHALL NOT EXCEED THE AMPACITY OF THE BUSBAR

(Required sign)

40 amp PV breaker

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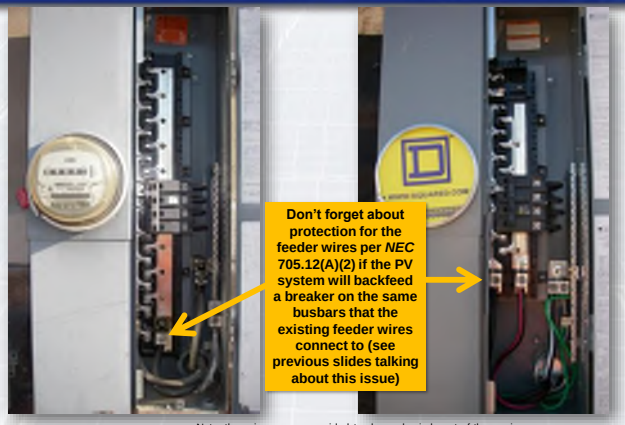
110

Method "4" (*NEC* 705.12(B)(4))

4) A connection at *either* end (but not both ends) of a **center-fed** panel board in dwellings is allowed where the sum of 125 percent of the power source(s) output circuit current and the rating of the overcurrent device protecting the busbar does not exceed 120 percent of the current rating of the busbar.

111

Center-Fed Busbars (dwellings)



Don't forget about protection for the feeder wires per *NEC* 705.12(A)(2) if the PV system will backfeed a breaker on the same busbars that the existing feeder wires connect to (see previous slides talking about this issue)

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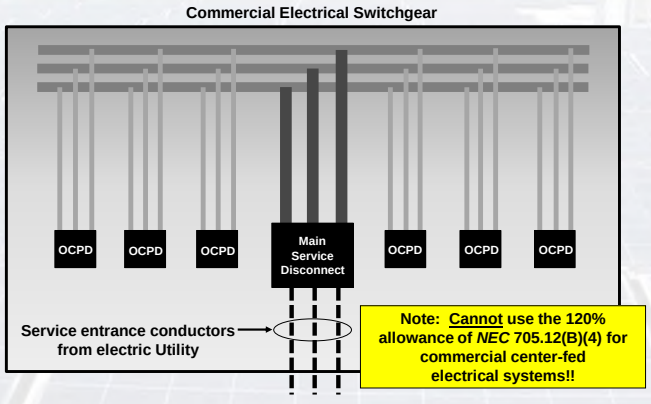
Note: these images are provided to show a basic layout of the service equipment. The intent is NOT to point out every code violation of the install.

112

Example Of Center-Fed Equipment:



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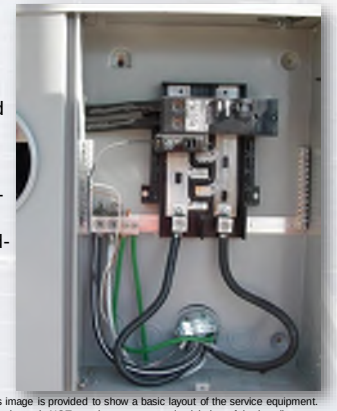
113

Method "5" (*NEC* 705.12(B)(5))

5) "Connections shall be permitted on busbars of panelboards that supply lugs connected to feed-through conductors. The feed-through conductors shall be sized in accordance with 705.12(A)."

"Where an overcurrent device is installed at either end of the feed-through conductors, panelboard busbars on either side of the feed-through conductors shall be permitted to be sized in accordance with 705.12(B)(1) through (B)(3)."



Note: this image is provided to show a basic layout of the service equipment. The intent is NOT to point out every code violation of the install.

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114

Method "6" (*NEC* 705.12(B)(6))

6) Connections made to switchgear, switchboards, and panelboards that are in configurations differing from *NEC* 705.12(B)(1) through (B)(5) are permitted as long as designed under engineering supervision that includes available fault-current and busbar load calculations.

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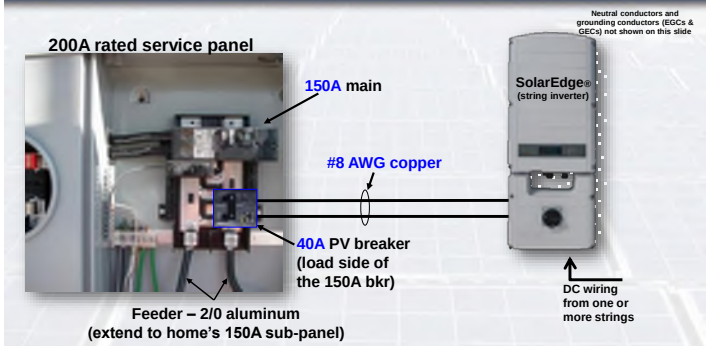
115

Example System



NEC 705.12(A)(2) and (B)(5) violation for the existing 2/0 feeders!
The 2/0 feeders need to be increased to 250kcmil OR a 125A breaker (or fused disconnect) must be added between the service and the existing sub-panel.

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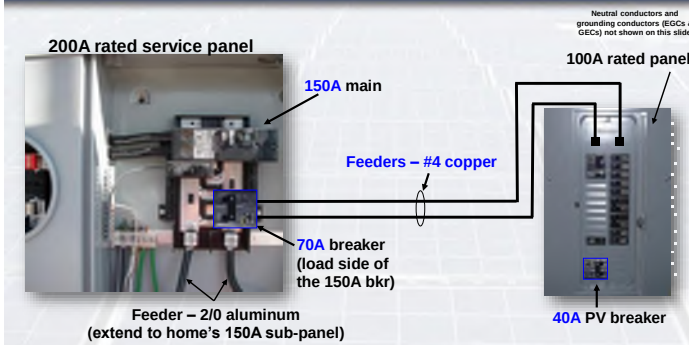
116

Example System



NEC 705.12(A)(2) and (B)(5) violation for the existing 2/0 feeders!

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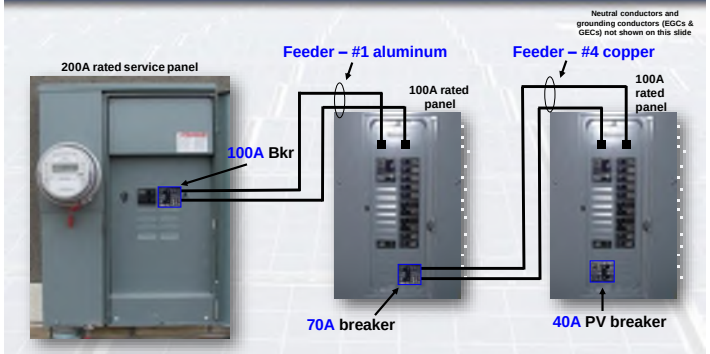
117

Example System



NEC 705.12(B) violation for the middle panel's busbars!

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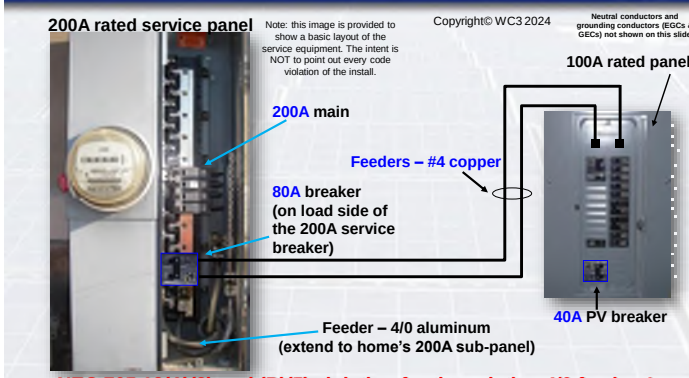
118

Example System



NEC 705.12(A)(2) and (B)(5) violation for the existing 4/0 feeders! Feeders either need to be upsized or must provide overcurrent protection between the service panel and the existing sub-panel.

119

705.13 – Power Control Systems

- **705.13:** "A power control system (PCS) shall be listed and evaluated to control the output of one or more power production sources, energy storage systems (ESS), and other equipment. The PCS shall limit current and loading on the busbars and conductors supplied by the PCS."
- **705.13(E):** "The access to settings of the PCS shall be restricted to qualified personnel in accordance with the requirements of **240.6(C)**."

Note: the requirements of *NEC* 705.13 moved to Article 750 in the 2023 *NEC* (for Energy Management Systems)

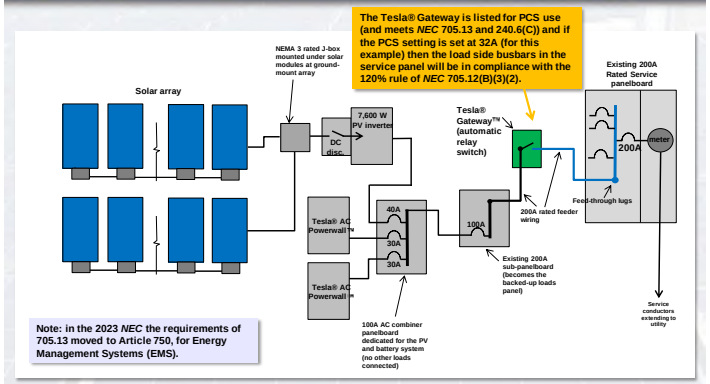
120

Power Control Systems (continued)

- **240.6(C)** requires restricted access to be achieved by one of the following methods:
  - (1) Located behind removable and sealable covers over the adjusting means
  - (2) Located behind bolted equipment enclosure doors
  - (3) Located behind locked doors accessible only to qualified personnel
  - (4) Password protected, with password accessible only to qualified personnel

121

Power Control System (PCS) Example



Note: this wiring diagram is simply an example and does not take into effect efficiency or ideal system design considerations. Diagrams may vary. ALWAYS FOLLOW MANUFACTURER'S REQUIREMENTS and APPLICABLE CODES.

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SolarEdge® Interface Equipment (PCS capability example)

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123

Example Plan Reviews of PV Systems

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124

Plan Review Example System #1

Enphase® IQ7+™ Micro Inverter System

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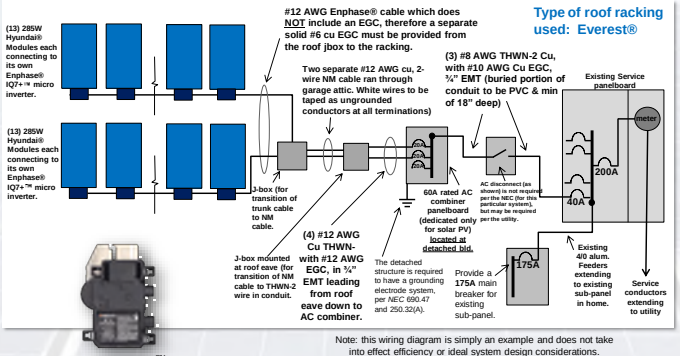
125

Example System (for an Enphase® IQ7+™ micro inverter system)

Example Sys. #1



Note: this wiring diagram is simply an example and does not take into effect efficiency or ideal system design considerations. Diagrams may vary. ALWAYS FOLLOW MANUFACTURER'S REQUIREMENTS and APPLICABLE CODES.

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126

Enphase® IQ6™ Micro Inverters

Example Sys. #1

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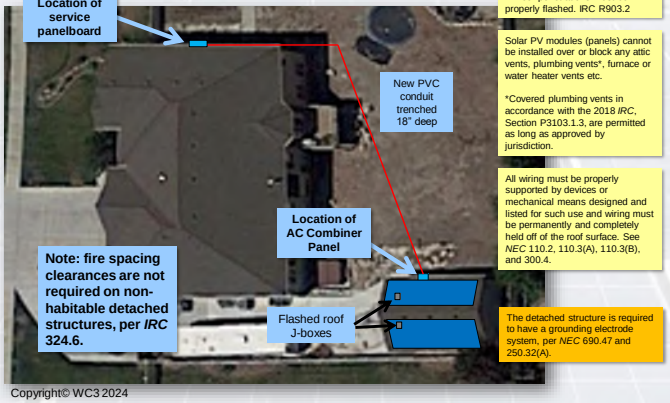
Install by Intermountain Wind and Solar

127

Site plan

Example Sys. #1



Note: fire spacing clearances are not required on non-habitable detached structures, per *IRC* 324.6.

All roof penetrations must be properly flashed. IRC R903.2

Solar PV modules (panels) cannot be installed over or block any attic vents, plumbing vents*, furnace or water heater vents etc.

*Covered plumbing vents in accordance with the 2018 *IRC*, Section P3103.1.3, are permitted as long as approved by jurisdiction.

All wiring must be properly supported by devices or mechanical means designed and listed for such use and wiring must be permanently and completely held off of the roof surface. See *NEC* 110.2, 110.3(A), 110.3(B), and 300.4.

The detached structure is required to have a grounding electrode system, per *NEC* 690.47 and 250.32(A).

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128

Photo of Service Panel

Example Sys. #1

Typically, photos of the service panel label are needed in order to show the rating of the service (and rating of breaker slots).

Also, a clear photo showing the rating of the main service breaker(s) is usually required (in order to determine load-side connection rules).

For this example, we are assuming that the service panel is rated for **200A** since the main service breaker is rated **200A**.

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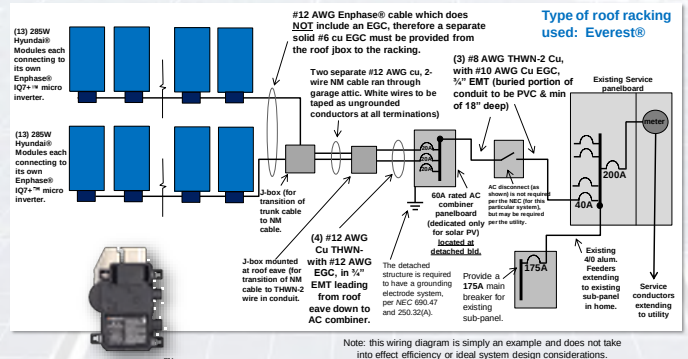
129

Example System (for an Enphase® IQ7+™ micro inverter system)

Example Sys. #1



Note: this wiring diagram is simply an example and does not take into effect efficiency or ideal system design considerations. Diagrams may vary. ALWAYS FOLLOW MANUFACTURER'S REQUIREMENTS and APPLICABLE CODES.

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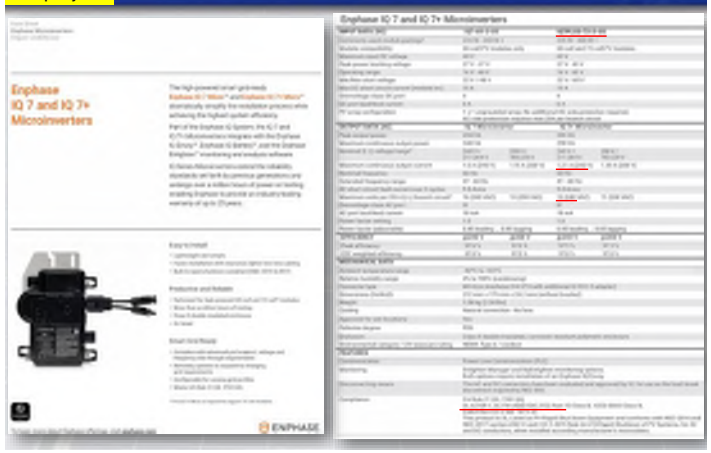
130

Enphase® IQ6+™ Specs

Example Sys. #1



131

Conductor Ampacity and OCPD Sizing

Example Sys. #1

1. Max current
NEC 690.8(A)(1)(c)

2. Breaker or fuse rating, and wire ampacity
NEC 690.8(B) and 690.9(B)

AC Circuit Wiring Between AC combiner Panel and Service	(inverters combined max output amps) 1.21amps × 26 micro inverters →	(inverters max output × 125%) 31.5A x 1.25= 39A A

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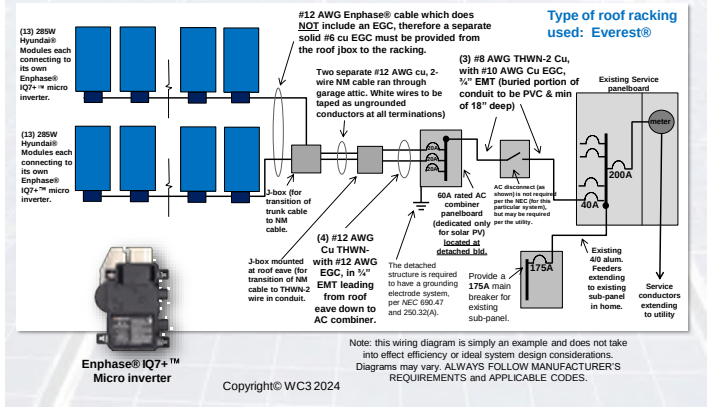
132

Example System (for an Enphase® IQ7+™ micro inverter system)

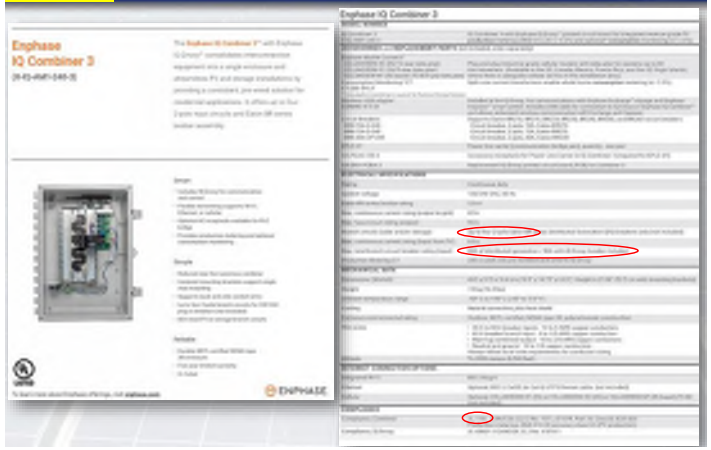
Example Sys. #1



133

Enphase® AC Combiner Panel (Enphase.com)

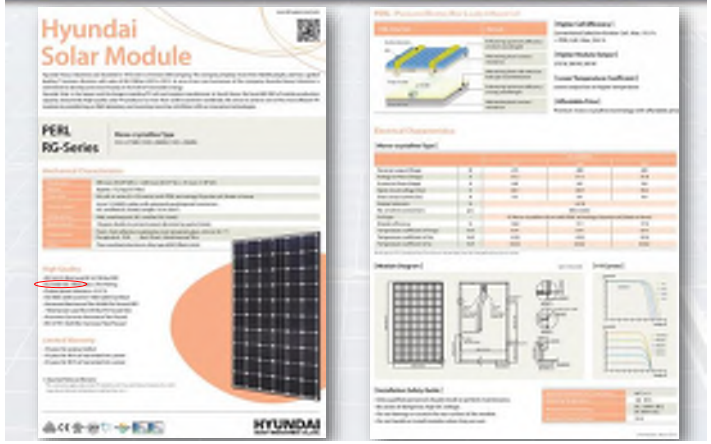
Example Sys. #1



134

Hyundai PV Module Specs (hhi-green.com/solar)

Example Sys. #1



135

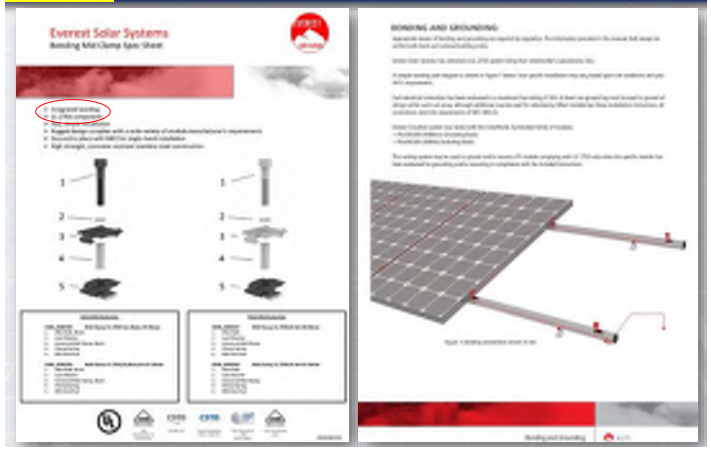
Everest® Racking Specs (Everest-solarsystems.com)

Example Sys. #1

136

Everest® Racking Specs (Everest-solarsystems.com)

Example Sys. #1



137

Signage

Example Sys. #1

All signage must be permanently attached and be able to withstand the environment they are installed. Signage also cannot be hand-written. *NEC* 110.21(B).

CAUTION: MULTIPLE SOURCES OF POWER

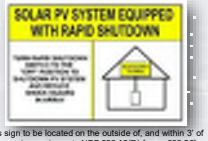
The above shown sign is required at the service disconnect. *NEC* 705.10.

WARNING: POWER SOURCE OUTPUT DO NOT RELOCATE THIS OVERCURRENT DEVICE.

This sign is required to be located next to the PV backfed breaker(s) **ONLY if** the 120% allowance of *NEC* 705.12(B)(2) is being utilized.

PV System:
AC Current = 30A
AC Volts = 240V

This sign is required to be located at the backfed panelboard. *NEC* 690.54 (of the **2020 NEC**).



This sign to be located on the outside of, and within 3' of the service equipment. *NEC* 690.12(D) [prev. 690.56].

RAPID SHUTDOWN SWITCH FOR SOLAR PV SYSTEM

This sign must be reflective and is required to be located next to the disconnect switch which activates rapid shutdown. *NEC* 690.12(D) [prev. 690.56(C)(2)]
(for this system, it could be at any AC breaker or AC disconnect that isolates the micro inverters from the utility grid when such breaker or disconnect is shut off)

WARNING ELECTRIC SHOCK HAZARD TERMINALS ON THE LINE AND LOAD SIDES MAY BE ENERGIZED IN THE OPEN POSITION.

This sign is required at disconnects where terminals can be energized even when the disconnect is shut off. *NEC* 690.13(B).

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138

Plan Review Example System #2

SMA® Sunny Boy™ String Inverter System

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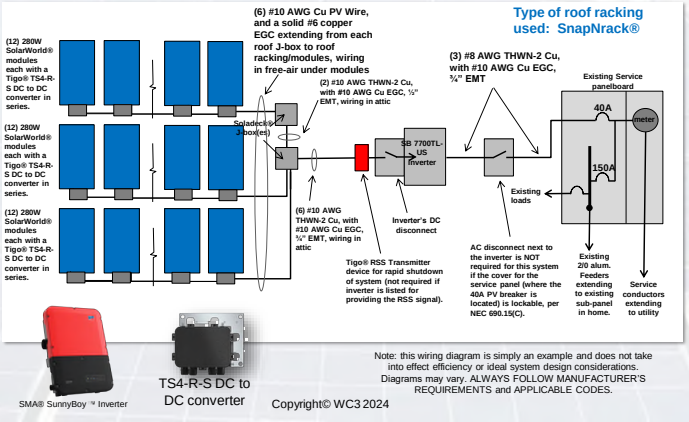
139

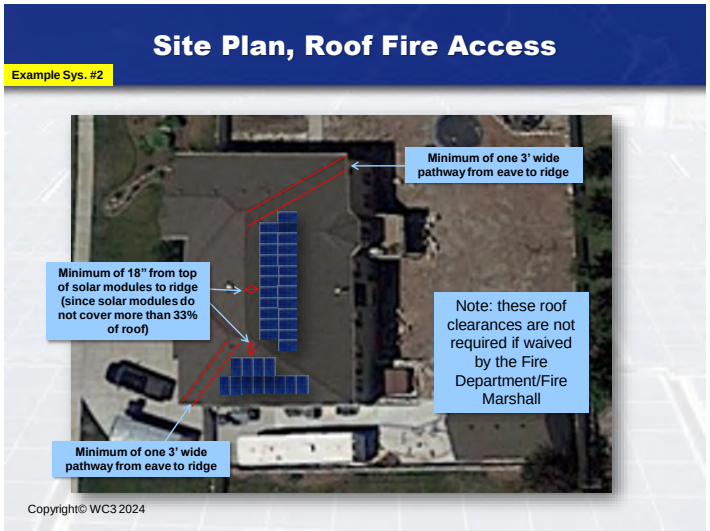
Example Single-Line Diagram (for an SMA® string inverter system)

Example Sys. #2

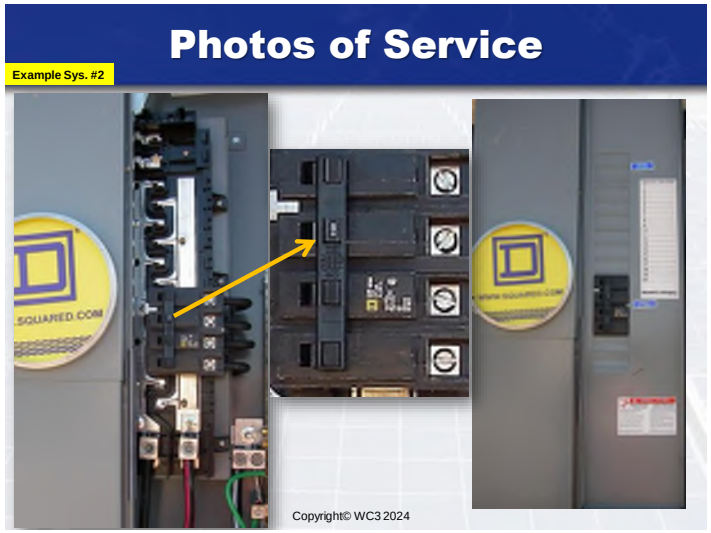


140

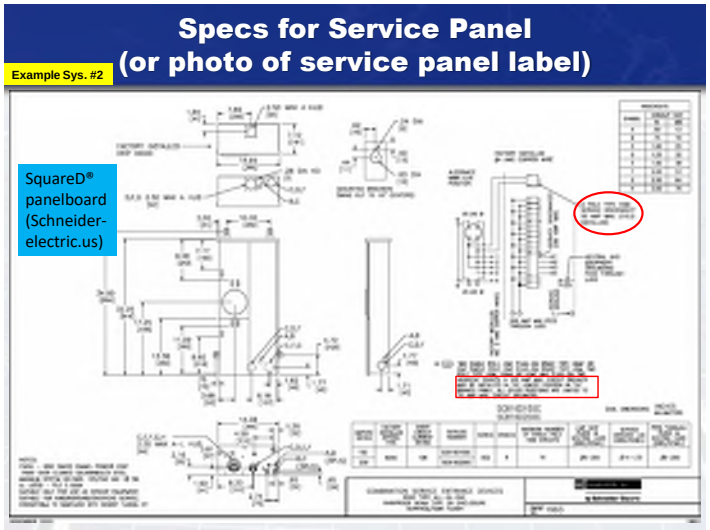
141



142



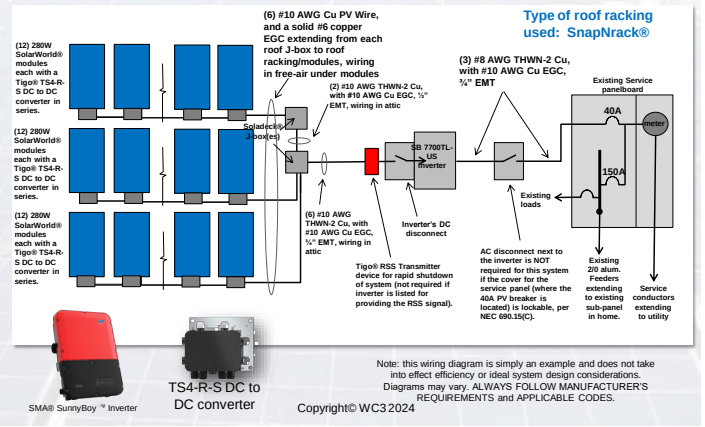
143



144

Example Single-Line Diagram (for an SMA® string inverter system)

Example Sys. #2



145

SMA® Spec Sheets (sma-America.com)

Example Sys. #2

146

SMA® Spec Sheets (sma-America.com)

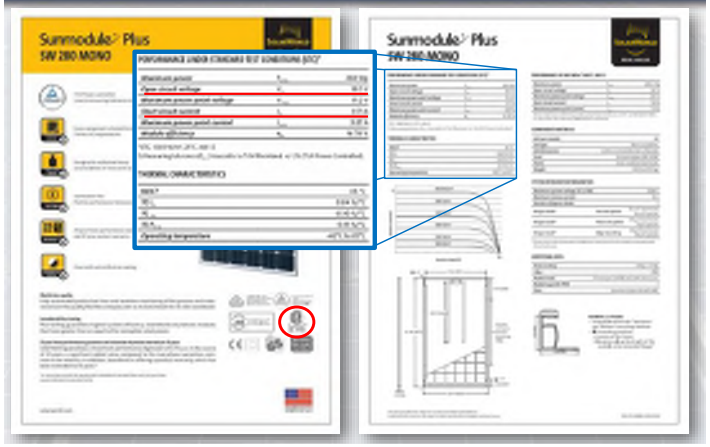
Example Sys. #2

Technical data	Sunny Boy 6.0-US		Sunny Boy 7.0-US		Sunny Boy 7.7-US	
	208 V	240 V	208 V	240 V	208 V	240 V
Input (DC)						
Max. PV power	9600 Wp		9940 Wp		10905 Wp	
Max. DC Voltage	600 V					
Rated MPP Voltage range	220 - 480 V		245 - 480 V		270 - 480 V	
MPPT operating voltage range	100 - 550 V					
Min. DC voltage / start voltage	100 V / 125 V					
Max. operating input current per MPPT	10 A					
Max. short circuit current per MPPT	18 A					
Number of MPPT tracker / string per MPPT tracker	3 / 1					
Output (AC)						
AC nominal power	5200 W	6000 W	6660 W	7000 W	6660 W	7680 W
Max. AC apparent power	5200 VA	6000 VA	6660 VA	7000 VA	6660 VA	7680 VA
Nominal voltage / adjustable	208 V / ●	240 V / ●	208 V / ●	240 V / ●	208 V / ●	240 V / ●
AC voltage range	183 – 229 V	211 – 264 V	183 – 229 V	211 – 264 V	183 – 229 V	211 – 264 V
AC grid frequency	60 Hz / 50 Hz					
Max. output current	25.0 A	25.0 A	32.0 A	29.2 A	32.0 A	32.0 A
Power factor (cos φ)	1					
Output phases / line connections	1 / 2					
Harmonics	< 4 %					
Efficiency						
Max. efficiency	97.3 %	97.7 %	97.3 %	97.9 %	97.3 %	97.5 %
CEC efficiency	96.7 %	96.9 %	96.4 %	96.8 %	96.4 %	96.8 %
Protection devices						
DC disconnect device / DC reverse polarity protection	● / ●					
Ground fault monitoring / Grid monitoring	●					
AC short circuit protection	●					
Allpole sensitive residual current monitoring unit (RCMU)	●					
Arc fault circuit interrupter (AFCI)	●					
Protection class / overvoltage category	I / IV					
General data						
Dimensions (W / H / D) in mm (in)	535 x 730 x 198 (21.1 x 28.5 x 7.8)					
Packaging Dimensions (W / H / D) in mm (in)	600 x 800 x 300 (23.6 x 31.5 x 11.8)					
Weight / packaging weight	26 kg (57 lb) / 30 kg (66 lb)					
Temperature range: operating / non-operating	-25°C ...+60°C / -40°C ...+60°C					
Environmental protection rating	NEMA 3R					
Noise emission (typical)	39 dB(A)		45 dB(A)			
Internal power consumption at night	< 5 W					

147

SolarWorld® PV Module Specs (solarworld-usa.com)

Example Sys. #2



148

Cold Temperature DC Voltage

Example Sys. #2

Maximum system DC voltage calculation:

Open Circuit Voltage (Voc) of modules= 39.5V DC (at 25˚C or 77˚F)

39.5V × 12 modules= **474V** (at 77˚F)

If we use -20˚C for our coldest temperature (which is noted in the ASHRAE Fundamentals Handbook for the SLC valley):

The difference in temperature drop from 25˚C to -20˚C is **45˚C**.

Per the modules specs, the voltage of the modules increases by .30% for every 1˚C.

Take 45˚C × .30 = a voltage increase of 13.5% at -20˚C.

474V × 1.135= a cold temperature voltage of **538V**.

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149

Conductor Ampacity and OCPD Sizing

Example Sys. #2

	1. Max current *NEC* 690.8(A)(1)(a-c)	2. Breaker or fuse rating, and wire ampacity *NEC* 690.8(B) and 690.9(B)
String circuit (source circuit)	(string Isc x 125%) 9.71 x 1.25= 12.14 A	(string max current x 125% again) 12.14 x 1.25= 15.2 A
~~PV output Circuit (circuit between DC combiner box and inverter)~~	~~(each strings' max DC current combined together) ___ x ___ (# of strings)= ___ A~~	~~(Total combined strings' max current x 125%) ___ x 1.25= ___ A~~
Inverter AC Output Circuit	(inverter max output) 32 amps	(inverter max output x 125%) 32 x 1.25= 40 A

Use the max amps in this column when starting the adjustment of wires for temp. and conduit fill. Take the larger of either the final adjusted ampacity from this column or the final amps in column 2 to size the conductors, *NEC* 690.8(B)(2).

If no deration or adjustment of wires is needed then use this column to size wire ampacity. Always use this column to size the breaker or fuses (use next size up breaker or fuse if between ratings).

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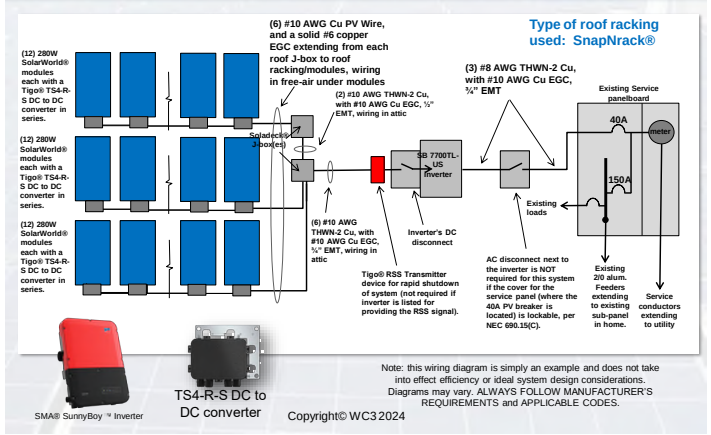
150

Example Single-Line Diagram (for an SMA® string inverter system)

Example Sys. #2



Note: this wiring diagram is simply an example and does not take into effect efficiency or ideal system design considerations. Diagrams may vary. ALWAYS FOLLOW MANUFACTURER'S REQUIREMENTS and APPLICABLE CODES.

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151

SMA® Rapid Shutdown Specs for Tigo® Optimizers (sma-America.com)

Example Sys. #2

152

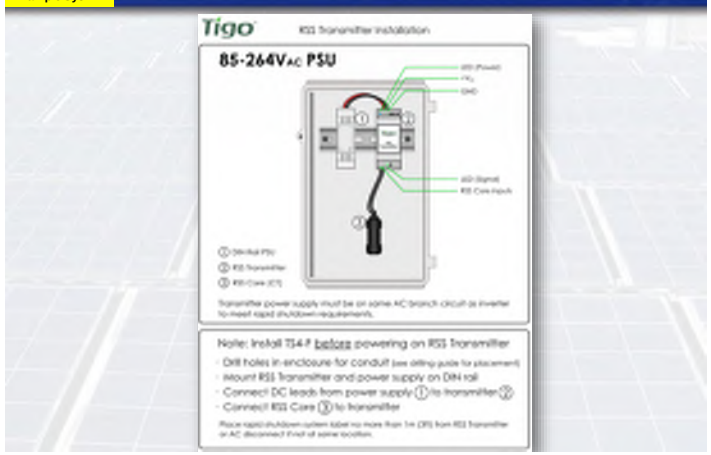
SMA® Rapid Shutdown Specs for Tigo® Optimizers (sma-America.com)

Example Sys. #2

153

SMA® Rapid Shutdown Specs for Tigo® Optimizers (sma-America.com)

Example Sys. #2



154

SnapNrack® Specs (snapnrack.com)

Example Sys. #2

155

SnapNrack® Wind Loading Tables (snapnrack.com)

Example Sys. #2

156

Signage

Example Sys. #2

All signage must be permanently attached and be able to withstand the environment they are installed. Signage also cannot be hand-written. *NEC* 110.21(B).

CAUTION: MULTIPLE SOURCES OF POWER

The above shown sign is required at the service disconnect. *NEC* 705.10.

PV System:
AC Current = 22A
AC Volts = 240V

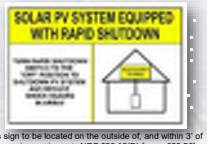
This sign is required to be located at the backfed panelboard. *NEC* 690.54 (per the **2020 *NEC***).

Maximum DC Voltage = 599V

This sign is required to be mounted on the **string** inverter. *NEC* 690.7(D) [prev. 690.54]

WARNING: POWER SOURCE OUTPUT DO NOT RELOCATE THIS OVERCURRENT DEVICE.

This sign is required to be located next to the AC PV backfed breaker(s) **ONLY if** the 120% allowance of *NEC* 705.12(B)(2) is being utilized.



This sign to be located on the outside of, and within 3' of the service equipment. *NEC* 690.12(D) [prev. 690.56].

RAPID SHUTDOWN SWITCH FOR SOLAR PV SYSTEM

This sign must be reflective and is required to be located next to the disconnect switch which activates rapid shutdown. *NEC* 690.12(D)(2) [prev. 690.56(C)(2)]
(for this system, it would be the 40A solar PV breaker located in the service meter panelboard)

PHOTOVOLTAIC POWER SOURCE

This sign is to be located on the outside of any conduits, enclosures, or MC cable that contain **DC** circuits. The markings shall **be reflective** and be provided at every enclosure, every 10' along conduit or MC cable, and at each side of where the conduit or cable passes through a wall, floor, or any other partition. The markings shall be permanently affixed and visible after installation. *NEC* 690.31(D)(2)

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Plan Review Example System #3

SolarEdge® HDwave™ String Inverter System – Ground Mounted PV

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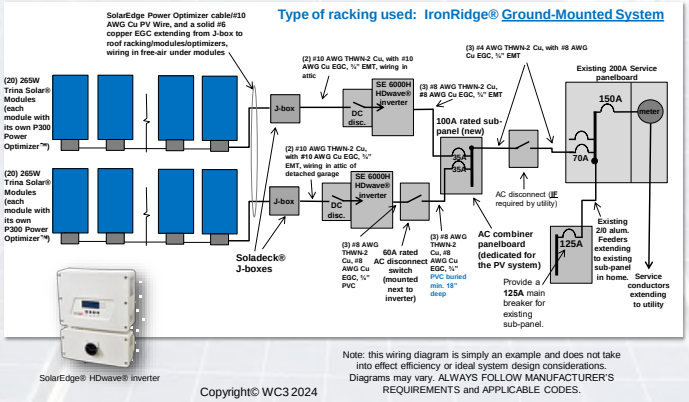
A SolarEdge® system (with two HDwave® SolarEdge® inverters)

Example Sys. #3

Type of racking used: IronRidge® Ground-Mounted System



Note: this wiring diagram is simply an example and does not take into effect efficiency or ideal system design considerations. Diagrams may vary. ALWAYS FOLLOW MANUFACTURER'S REQUIREMENTS and APPLICABLE CODES.

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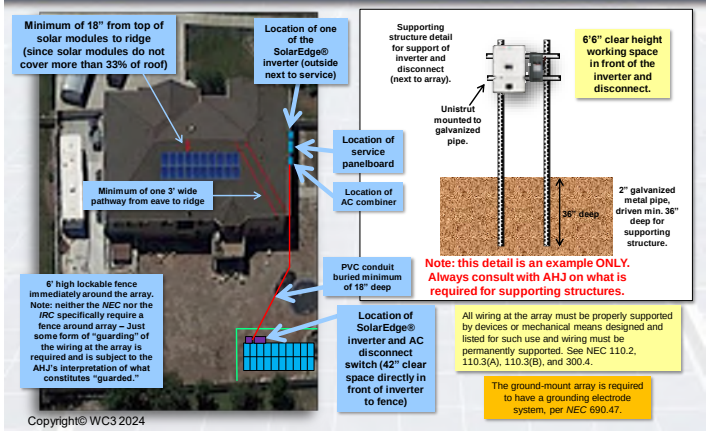
Site plan

Example Sys. #3



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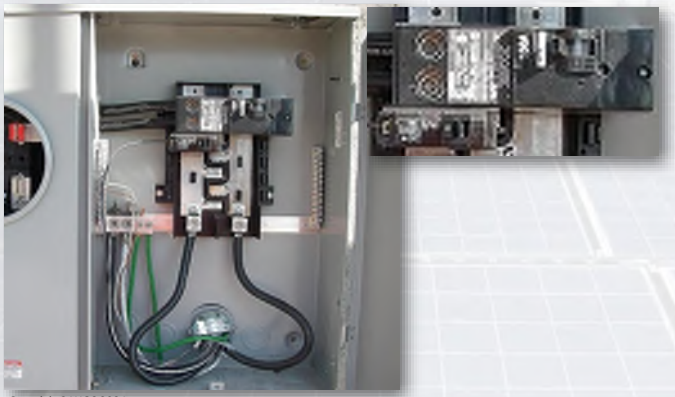
Photos of Service Panel

Example Sys. #3



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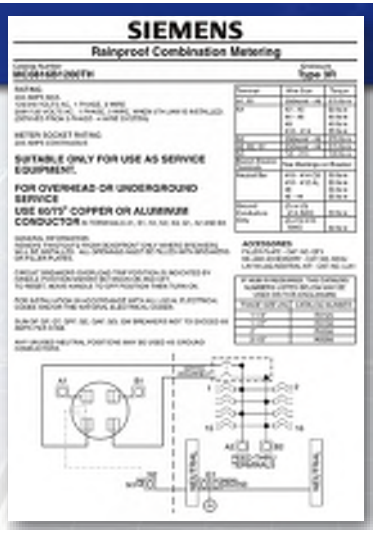
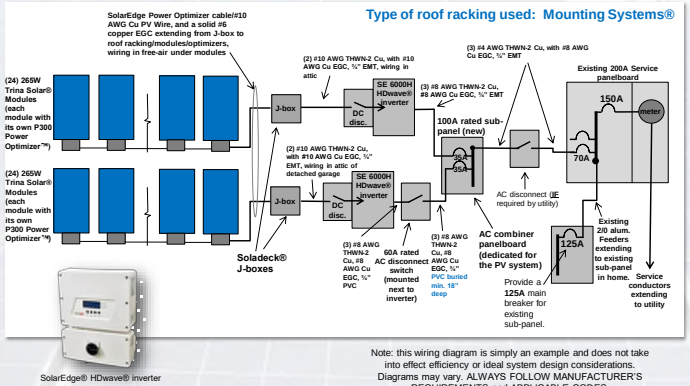


Specs for the Siemens® MC0816B1200TH service panelboard (Siemens.com)

162

A SolarEdge® system (with two HDwave® SolarEdge® inverters)

Example Sys. #3



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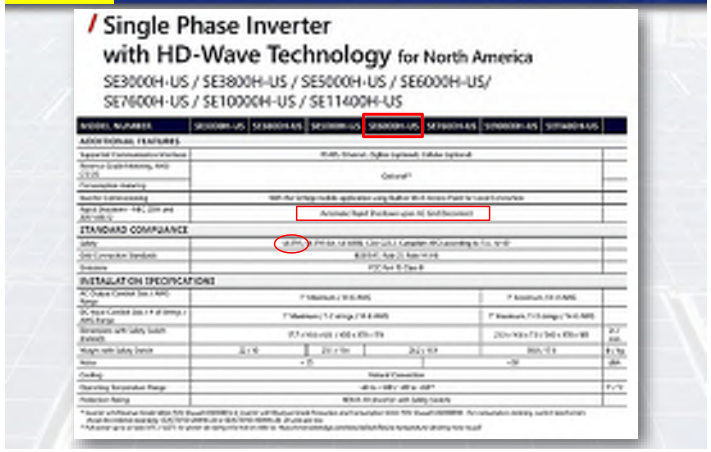
Inverter Specs (solaredge.com)

Example Sys. #3

164

Inverter Specs (solaredge.com)

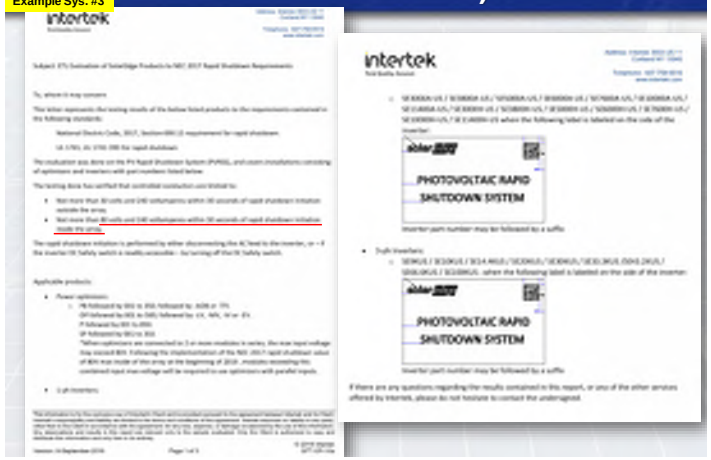
Example Sys. #3



165

Inverter Certification (SolarEdge.com and Intertek.com)

Example Sys. #3



166

SolarEdge® Power Optimizer™ Specs (solaredge.com)

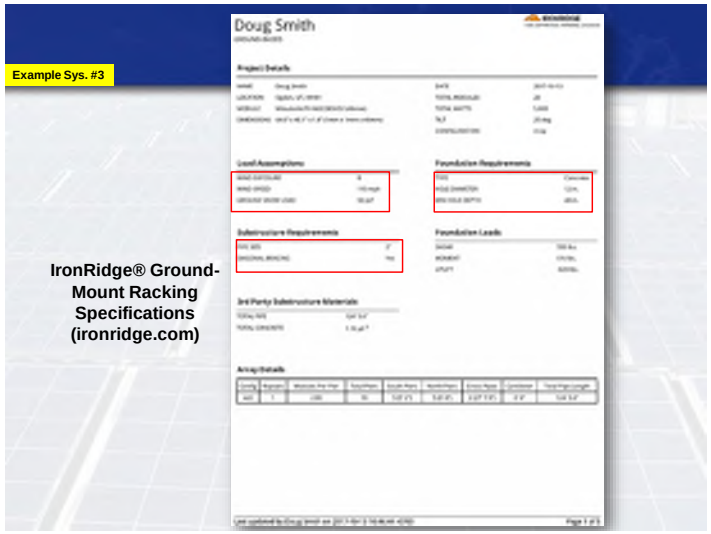
Example Sys. #3

167

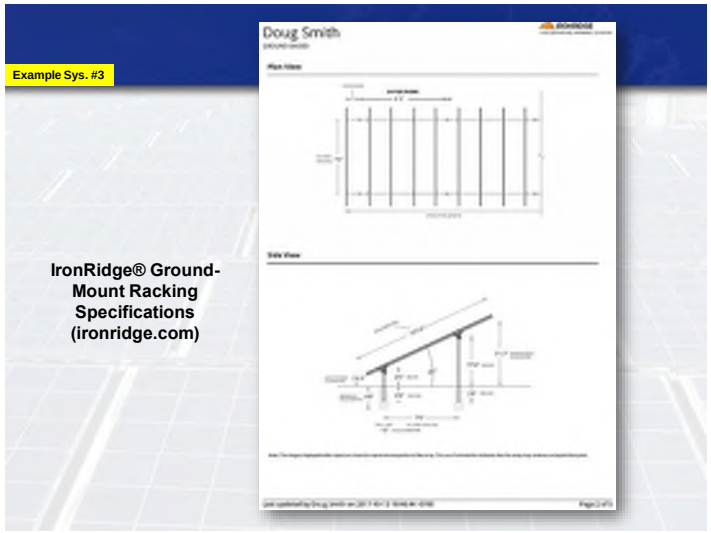
Solar PV Module Specs (trinasolar.com)

Example Sys. #3

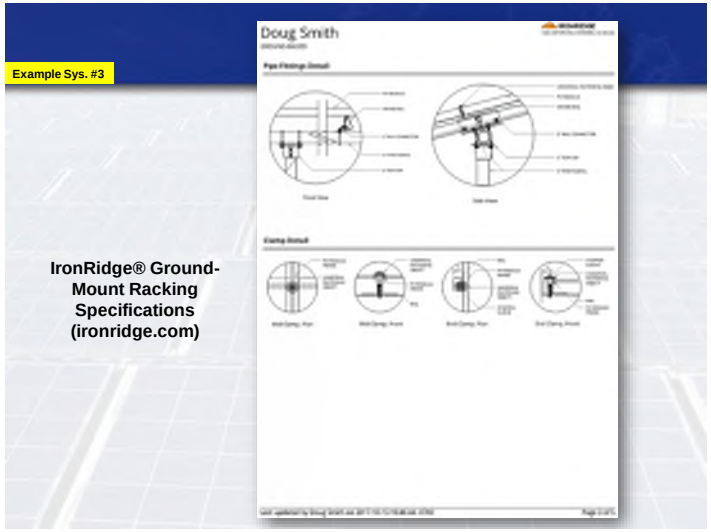
168



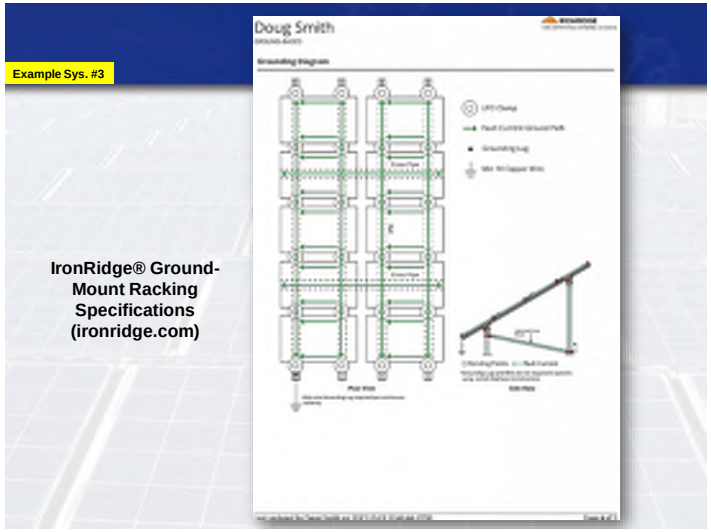
169



170



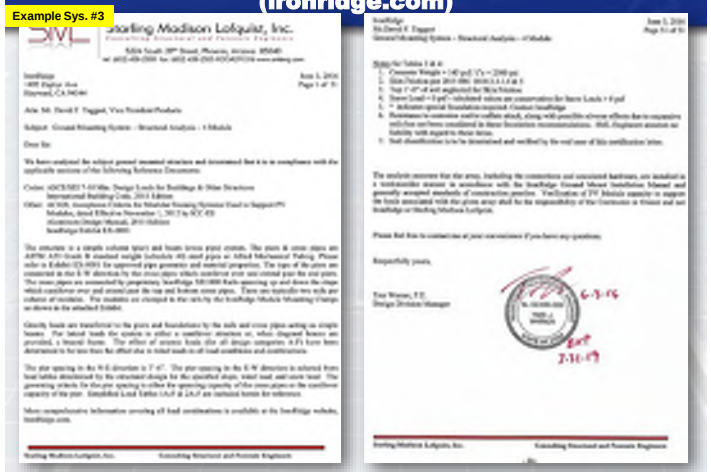
171



172

IronRidge® Ground-Mount Racking Specifications (ironridge.com)

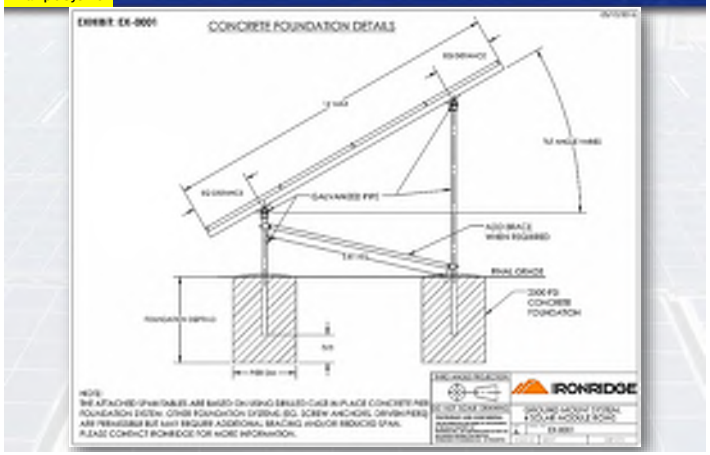
Example Sys. #3



173

IronRidge® Ground-Mount Racking Specifications (ironridge.com)

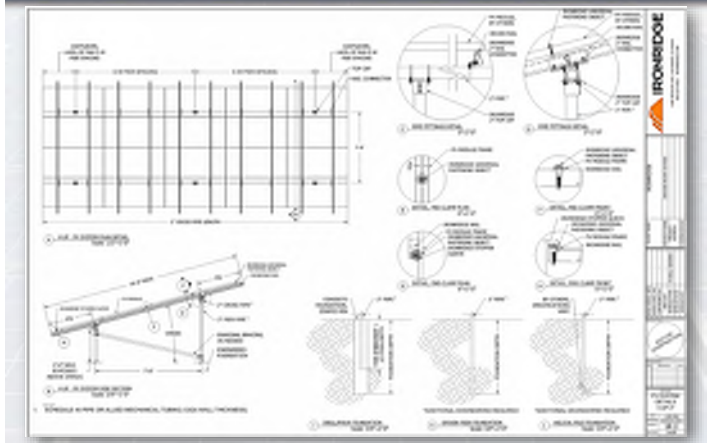
Example Sys. #3



174

IronRidge® Ground-Mount Racking Specifications (ironridge.com)

Example Sys. #3



175

Signage

Example Sys. #3

All signage must be permanently attached and be able to withstand the environment they are installed. Signage also cannot be hand-written. *NEC* 110.21(B).

CAUTION: MULTIPLE SOURCES OF POWER

The above shown sign is required at the service disconnect. *NEC* 705.10.

Note: 2[redacted] PV inverter is located at ground-mounted solar array behind home.

A sign is required at the home's service meter panelboard noting the location of the 2nd **string** inverter since it's not located next to the utility service panel. *NEC* 690.4(D). Wording could vary.

Maximum DC Voltage = [redacted]

This sign is required to be mounted on the **string** inverter. *NEC* 690.7(D) [prev. 690.53]

WARNING: POWER SOURCE OUTPUT DO NOT RELOCATE THIS OVERCURRENT DEVICE.

This sign is required to be located next to the AC PV backfed breaker(s) **ONLY if** the 120% allowance of *NEC* 705.12(B)(2) is being utilized.

PV System:
AC Current = 50A
AC Volts = 240V

This sign is required to be located at the backfed panelboard. *NEC* 690.54 (in the **2020 *NEC***).

SOLAR PV SYSTEM EQUIPPED WITH RAPID SHUTDOWN

This sign to be located on the outside of, and within 3' of the service equipment. *NEC* 690.12(D) [prev. 690.56(C)(1)].

RAPID SHUTDOWN SWITCH FOR SOLAR PV SYSTEM

This sign must be reflective and is required to be located next to the disconnect switch which activates rapid shutdown. *NEC* 690.121(D) [prev. 690.56(C)(2)]

(for this system, it would be at the 70A tie-in breaker in the service or the PV AC disconnect switch near service – if provided)

PHOTOVOLTAIC POWER SOURCE

This sign is to be located on the outside of any conduits, enclosures, or MC cable that contain **DC** circuits. The markings shall **be reflective** and be provided at every enclosure, every 10' along conduit or MC cable, and at each side of where the conduit or cable passes through a wall, floor, or any other partition. The markings shall be permanently affixed and visible after installation. *NEC* 690.31(D)(2)

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Solar PV Inspections

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Roof-Mounted PV Systems

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Roof Access Pathways

For detailed residential roof access pathway requirements, see previous slides in this presentation.

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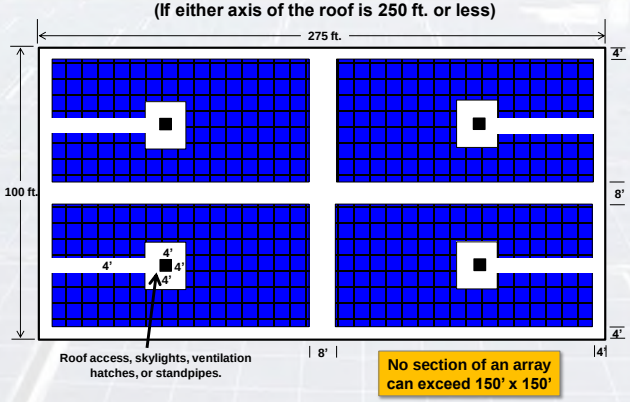
2021 *IFC* Required Pathways On Non-Residential Roofs (1205.3.1-1205.3.3)

(If either axis of the roof is 250 ft. or less)



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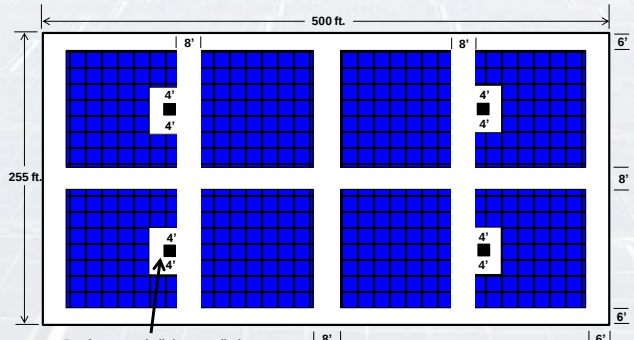
2021 *IFC* Required Pathways On Non-Residential Roofs (1205.3.1-1205.3.3)



No section of an array can exceed 150' x 150'

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Example of Roof Access Pathway

Install by Hunt Electric

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Locations of Solar Modules On Roof

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Roof Installations

- Most jurisdictions do not allow PV modules to be installed over any plumbing, mechanical, or other types of vents.
- Modules must not be installed over any openings or equipment that are required to remain accessible.

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Covering Roof Plumbing Vents?

- *IRC* P3103.1.3 (of the 2021 *IRC*) says:
  - "Where an open vent pipe terminates above a sloped roof and is covered by either a roof-mounted panel (such a solar collector or PV panel…) or a roof element…, the vent pipe shall terminate not less than 2 inches about the roof surface. Such roof element shall be designed to prevent the adverse effects of snow accumulation and wind on the function of the vent. The placement of a panel over a vent pipe and the design of a roof element covering the vent pipe shall provide for an open area for the vent pipe to the outdoors that is not less than the area of the pipe, as calculated from the inside diameter of the pipe. Such vent terminals shall be protected by a method that prevents birds and rodents from entering or blocking the vent pipe opening."

185

Roof Installations (continued…)

Vent re-routing by Solar Roof Jack®

186

Roof Racking Support and Flashing

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Roof Racking Supports

- Roof racking supports must be spaced no more than the maximum spans allowed per the racking manufacture.
- Also, spacing of supports may be required to be closer together when they are located close to the edges or peak of the roof.
- In addition, most engineers require that supports be reasonably staggered from one row of rails (or modules) to the next so not all supports are not sitting on the same trusses.

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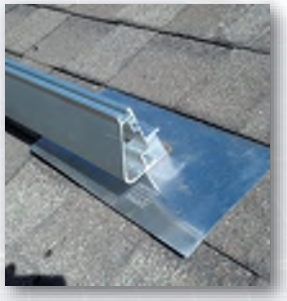
Roof Flashings

All roof penetrations must be properly flashed or use other listed methods of sealing penetrations. *IRC* 903.2

SolaDeck box (RSTC Enterprises, Inc.)



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Sealing of Roof Penetrations

QuickBOLT®

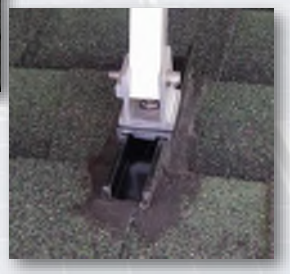
SnapNrack®

Unirac®

Roof attachment methods should be evaluated for preventing water entry and must be installed per their installation instructions.

190

Proper Sealing of Roof Penetrations Is Required!



Violations!

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Sealing Roof Penetrations Required

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Sealing of Roof Penetrations

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Sealing Roof Penetrations

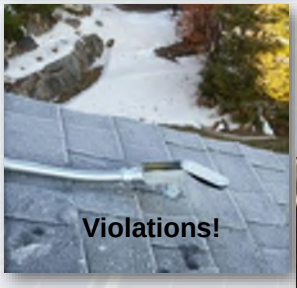
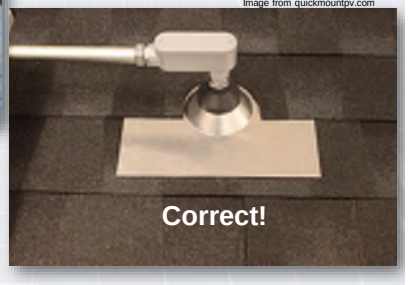


Image from quickmountpv.com



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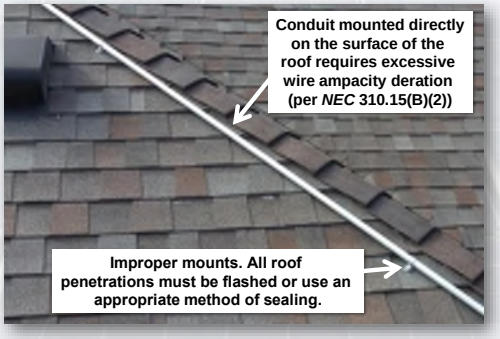
Improper Conduit Installation



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Sealing Roof Penetrations

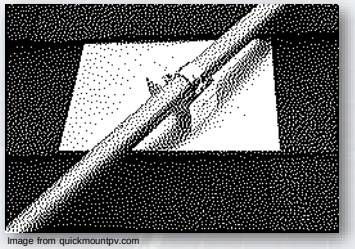

Image from quickmountpv.com

SnapNrack® flashed conduit support

196

Do I really need to note that there's violations here?!

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Great example……. of what NOT to do!

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Ballasted Racking Systems

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Number of Ballast Blocks Per Racking Tray Must be Per Racking Manufacturer's Requirements

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Structural Integrity

201

Wiring at Array

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Wiring Under Modules

All wires must be neatly tucked up under the modules or in the rails to protect from water and ice damage. *NEC* 300.4

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Installation Errors

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Installation Errors

Violations!

Image courtesy of Frank Sonnabend

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Good Wire Management

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Poor Wire Management

Wiring (including equipment grounding conductors) must be protected in conduit or enclosures when not directly under solar modules. *NEC* 300.4

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Poor Wire Management

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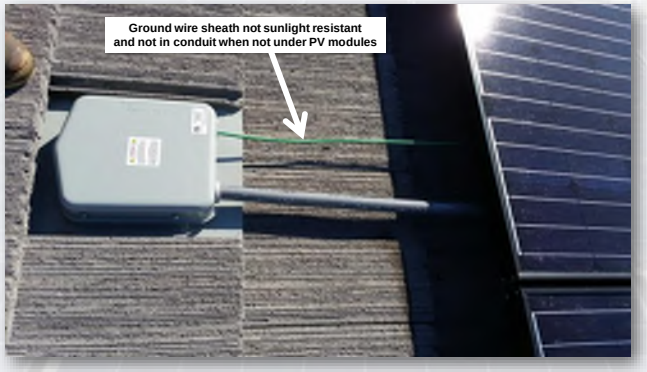
Installation Errors



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Installation Errors

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Corrected

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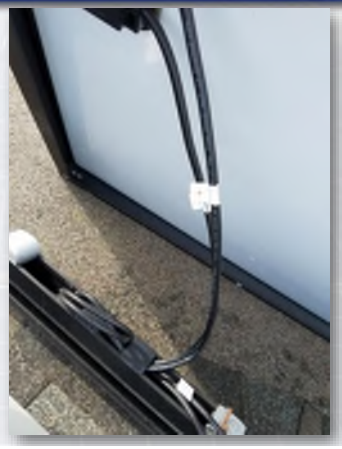
Wire Management

Some racking systems provide channels for wiring to be installed within.

Wiring must be installed so not subject to any sharp edges and wiring must maintain its required bending radius (no kinks!).



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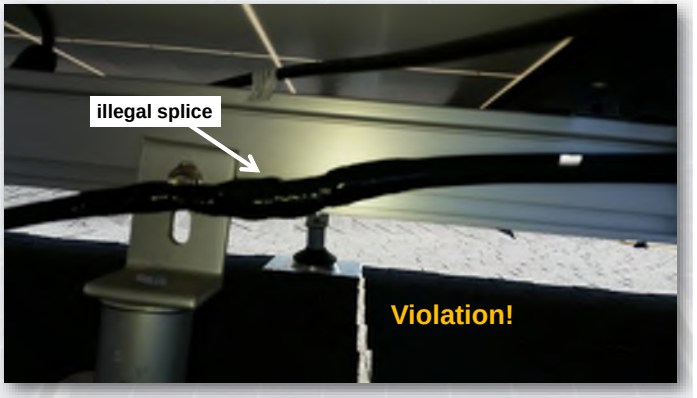
Installation Errors



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Corrected

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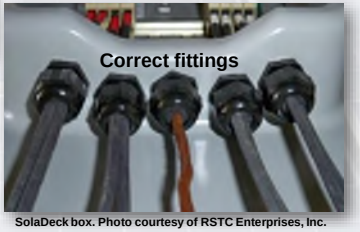
Strain Relief Fittings

Wires installed outdoors must be secured when entering boxes or equipment with listed weather proof strain relief connectors. *NEC* 300.16(A)



SolaDeck box. Photo courtesy of RSTC Enterprises, Inc.

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Violations!

Can't have more than one wire per lug (unless lug is designed and listed for such)

Wire entering box without a strain relief fitting

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Good Wire Management

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Wire Management

Inverters mounted on the roof should be mounted as close as possible to the solar modules (panels) to minimize exposure of wiring to physical damage.

Otherwise, a listed wire management system may be needed for the wiring extending from the array to the inverter.

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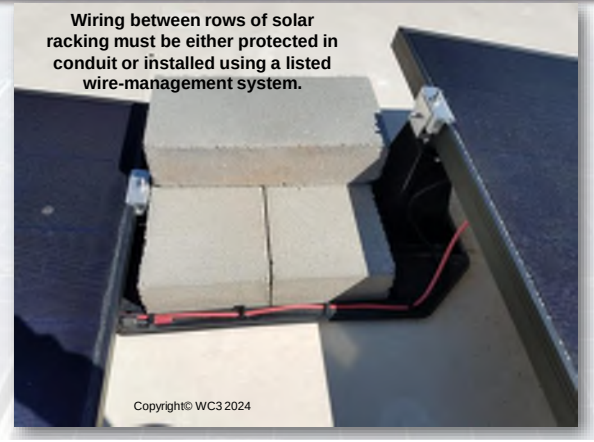
Wire Management

Wiring between rows of solar racking must be either protected in conduit or installed using a listed wire-management system.



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Wire Management

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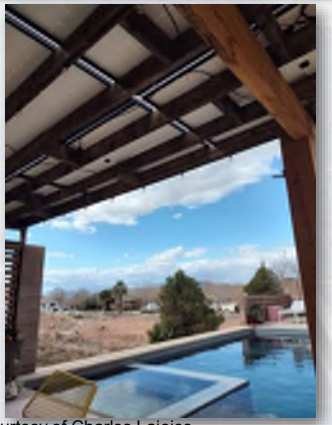
Installation Errors



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Images courtesy of Charles Lajoice

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Systems must be maintained in a safe condition (*IFC* 603)

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Grounding and Bonding at the Array

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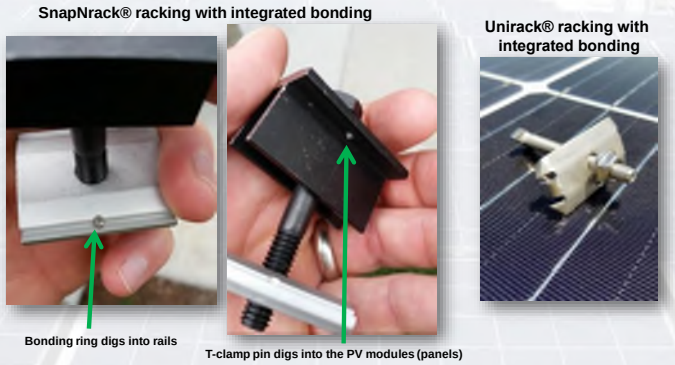
Racking With Integrated Bonding



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Racking With Integrated Bonding

- Racking systems should be listed per UL 2703.
- Parts designed for bonding should be tested per UL 467.

SnapNrack® racking with integrated bonding

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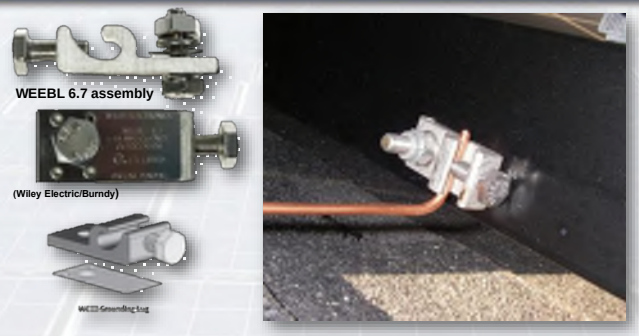
Bonding to Support Rails



Metal parts of the PV system are required to be bonded to the equipment grounding conductor. *NEC* 690.43.

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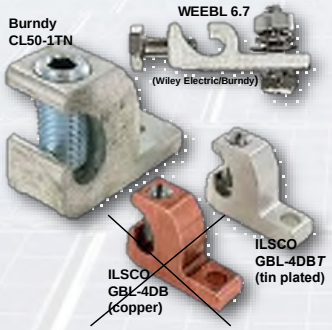
Listed "Lay-In" Lugs For Bonding Rails Or Modules



- Module manufacturer should provide instructions on how to properly ground/bond their modules and specify the hardware or equipment that should be used.
- Verify that the lay-in lugs or connectors are listed and approved to be installed in direct contact with aluminum AND be installed outdoors.

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Listed Lay-in Lug

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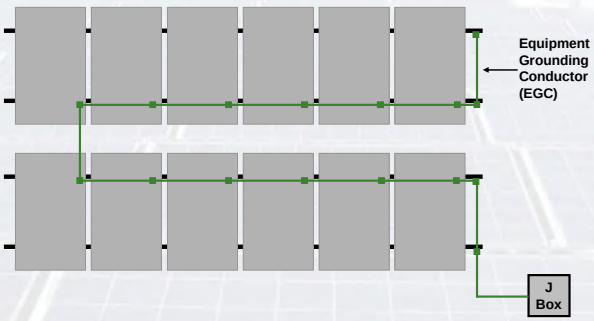
Bonding Supports And Modules



If listed integrated grounding/bonding T-clamps or WEEB washers (or other listed bonding devices) are not used, each module and each rail must be connected to the equipment grounding conductor.

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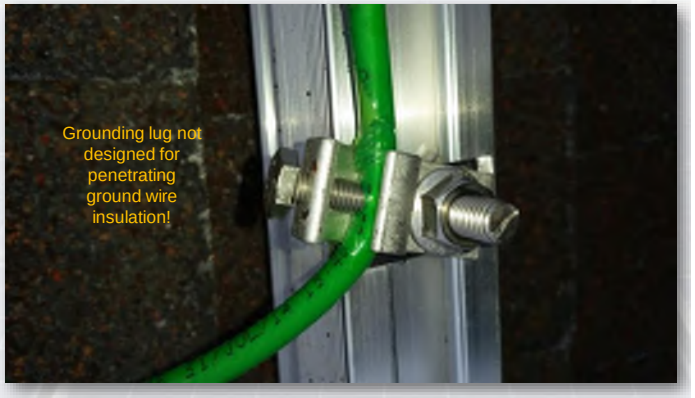
Installation Errors



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Improper Bonding

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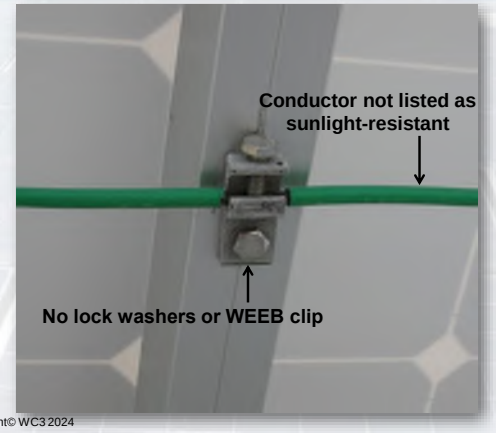
Improper Bonding



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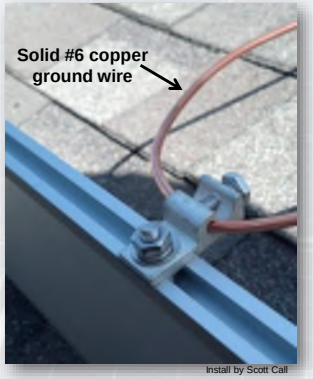
Grounding Lug



Proper grounding lug connection

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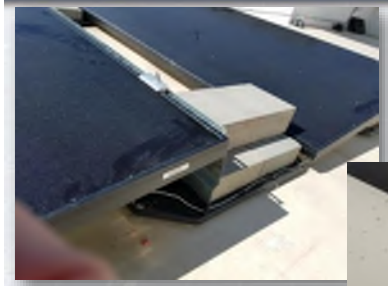
Bonding at Array



Devices or equipment that bond solar modules (panels) together must be listed for the application. *NEC* 690.43(A).

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Bonding at Conduit

Verify that any bond bushings and ground lugs used outdoors are listed for wet locations (they will often also be listed for direct burial). *NEC* 110.3(B).

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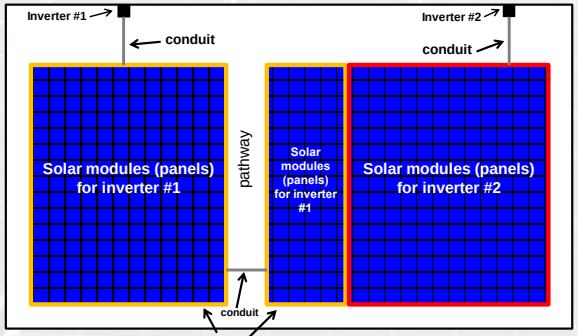
Installation Errors

237

Required Equipment Grounding Conductor Must Extend to Inverter

The equipment grounding conductor(s) which connect to racking and solar modules (and other metal parts) must extend to the inverter served!



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Rapid Shutdown

For additional detailed rapid shutdown requirements (per *NEC* 690.12), see previous slides in this presentation.

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SolarEdge® String inverters

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Example of SolarEdge® Power Optimizers behind solar panels.

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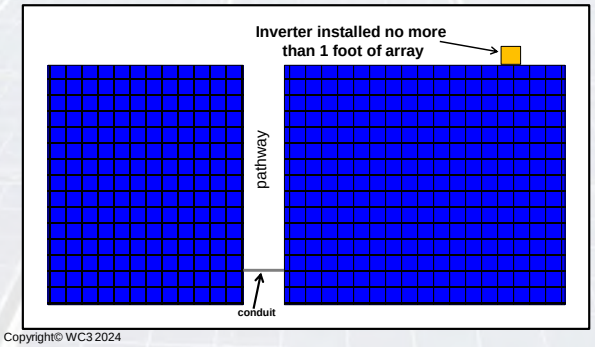
Non-Residential Buildings

There are currently on the market PV systems available which are listed UL 3741 as a PV Hazard Control System. Such systems often require the inverter to be installed within 1 foot of the solar array.
ALWAYS follow the manufacturer's installation instructions!!



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Ground-Mounted PV Systems

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Wire Protection
(where DC conductors are readily accessible)

Wires located in readily accessible locations shall be installed in raceways, MC cable, or be guarded, *NEC* 690.31(A).

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Barrier around the array?

Would this be a legitimate fence or "barrier" around the array? What say you?

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Barrier around the array?

How about this one? Would this one be a legitimate fence or "barrier" around the array?

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"Guarded" Wiring?

Ground-mount solar array – are wires "guarded"?

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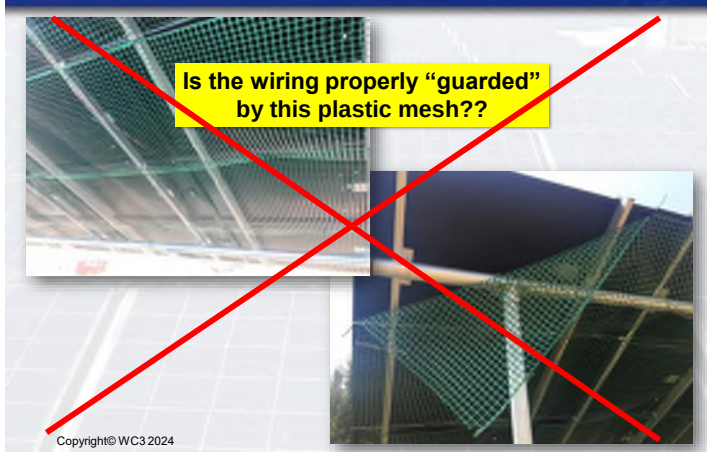
Covering on back of solar modules??



249

250

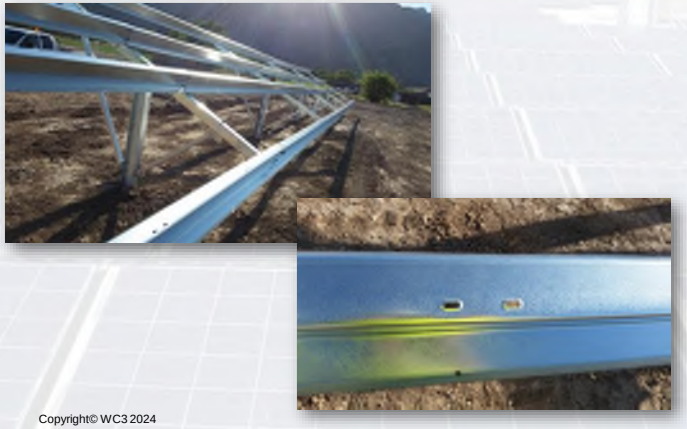
Proper support of wiring, even at ground-mount arrays, is important!

251

Wire protection at a ground-mount array

252

Ground-Mounted System Racking With Integrated Bonding



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Ground-Mounted System Racking With Integrated Bonding

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Grounding and Bonding

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Equipment at the array

System installed by Ken Gardner

Equipment (such as inverters, disconnects, etc) mounted at a ground-mount array must be rigidly secured in place and must have a 6'6" clear headroom and clear working space directly in front of the equipment. *NEC* 110.26(A)

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Equipment at the array

Equipment must be protected from damage. *NEC* 110.27(B)

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Incorrect Ground Mount System

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Incorrect Ground Mount System

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Clearance to Grade

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Point of Interconnection

For detailed point of interconnection requirements per *NEC* Article 705, see previous slides in this presentation.

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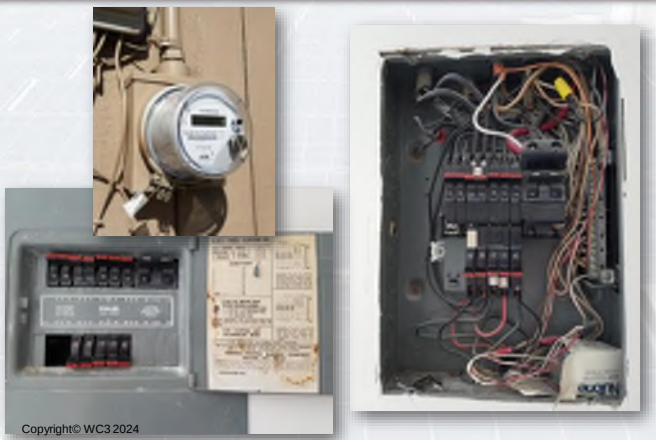
Service upgrades on old homes?????



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Existing Illegal Wiring and Connections – A BIG PROBLEM!

- Most jurisdictions require improper or illegal electrical connections to be corrected prior to the connection of the solar PV system.

Several illegal feeder taps shown in this example

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Illegal Modification of Panel Cover

It's not okay to cut or modify a panel cover!

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Existing Illegal Wiring (continued…)

Existing illegal code violations need to be corrected!

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Illegal modifications of service panel!!

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Modifications of Equipment?

Cannot drill or modify electrical equipment unless permitted per the manufacturer's instructions, or the modification must be field evaluated for the application (and be field labeled). *NEC* 110.3(B) and 705.11(C)(2).

267

General Equipment Requirements

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Working space in front of equipment

2023 *NEC* 110.26(A)(6) clarifies that the grade, floor, or platform for the required working space must be kept clear and be as flat and level as practical.

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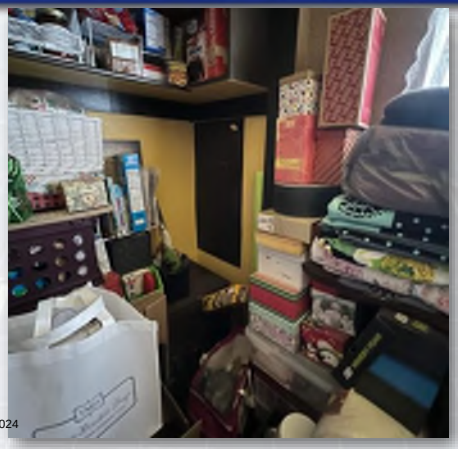
Working space in front of equipment?



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Listing of PV Equipment, *NEC* 690.4(B)

Verify that solar modules are listed per UL 1703 (or UL 61730)

Verify that inverters, converters, and controllers are listed per UL 1741.

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Disconnects From All Sources

***NEC* 690.15(C) requires disconnects for inverters from all sources of power.**

The required disconnect(s) must be within sight and within 10' of the equipment unless the disconnecting means is lockable or located behind a cover that can be locked.

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Some Inverters Have Both a DC and an AC disconnect Provided

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Mounting of equipment

Equipment must be properly mounted to a suitable surface and be well secured in place. *NEC* 110.3(B) and 110.13(A)

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Equipment located above or below other equipment

Electrical equipment is permitted to be installed above or below other electrical equipment (if they are associated with the same system), but one piece of equipment cannot project more than 6" from the front of the other adjacent equipment. *NEC* 110.26(A)(3)

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Fuses at DC Combiners

Verify that all fuses at a DC combiner are listed for PV use (see *NEC* 690.9(B)) and are rated for the maximum voltage of the system (*NEC* 110.3(B))

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Production Meters

Some utilities and jurisdictions require an extra meter base so a production meter can be added for a PV system. Such meter bases must be listed.

Also, if feeder taps are to be performed in order for connection of the PV system with the home's electrical system, the taps must first extend to an overcurrent protection device (an OCPD such as a fused disconnect) and then the meter base can be added on the load side of such OCPD (ie. the meter base cannot be between the point of taps and the OCPD for the taps). See *NEC* 240.21(B).

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Equipment must be outdoor rated when outside (*NEC* 110.28)!

This panelboard is <u>not</u> outdoor rated!

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Equipment Violations

Do I really need to explain why this is NOT okay??

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General Wiring Requirements

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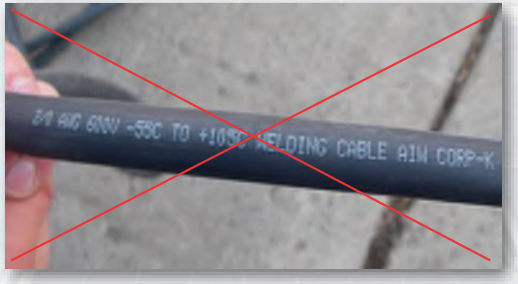
Fine-Stranded Cable



Welding cable and automobile cable is <u>not</u> a recognized wiring method In the *NEC*.

There are USE/RHW and THW fine-stranded cables that are available for battery use.

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Fine Stranded Wires

Conductors more finely stranded than class B or C:

- If fine stranded wires are used they must have terminals identified and listed for such, *NEC* 110.14.
- The connectors must meet UL 486 A & B (manufacturer listing and installation info is required).

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See *NEC* 110.14 and Chapter 9, table 10 for more info on fine stranded conductors.

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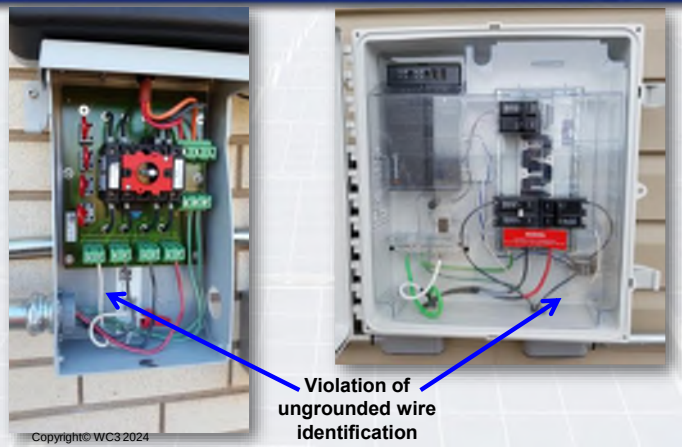
Identification of Ungrounded Wiring (*NEC* 310.6 and 200.7(C))



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Conductors of Different Systems

2023 *NEC*, 690.31(B)(1) – Conductors of Different Systems:

- If allowed per equipment's listing, PV dc circuits are permitted to occupy the same equipment wiring enclosure, cable, or raceway with non-PV systems or inverter ac output circuits.

285

Conductors of Different Systems Continued…

2023 *NEC*, 690.31(B)(1) continued…

- Where all conductors or cables have an insulation rating per the maximum system voltage, the following is allowed:
  - Multiconductor jacketed cables for signaling or power-limited circuits for PV systems are permitted to be located in the same conduit (raceway), cable assembly, or enclosure as PV dc circuits.
  - Inverter output (ac) circuits are allowed to occupy the same junction box, pull box, or wireway as PV dc circuits as long as the dc circuits are grouped and identified per 690.31(B)(2) and (B)(3).
  - PV dc circuits are permitted to occupy the same wiring method as inverter output (ac) or non-PV system circuits as long as the dc wiring is part of multiconductor jacketed cables, MC cable, or listed wiring harnesses.

286

Conductors of Different Systems Continued…

The 2023 *NEC* allows for dc and ac conductors to be in the same wireway (see *NEC* 690.31(B)(1)).

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Example: Separation of DC Wiring From AC Wiring

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Example: Separation of DC Wiring From AC Wiring

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DC Wiring Within A Building

DC wires entering the home or building must be in metal conduit or be MC cable. *NEC* 690.31(D) – see exception for listed PV hazard control systems.

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Wiring Within A Building

Nonmetallic sheathed cable may be left exposed inside a home only with micro inverter or AC module systems and if protected from damage (this may also apply to commercial buildings if nonmetallic sheathed cable is permitted.

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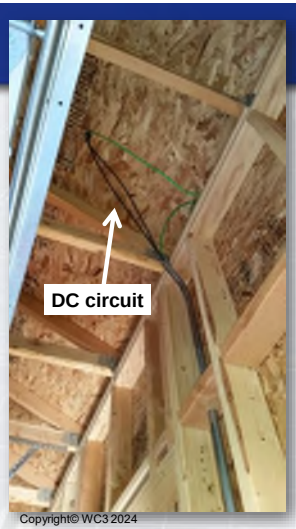

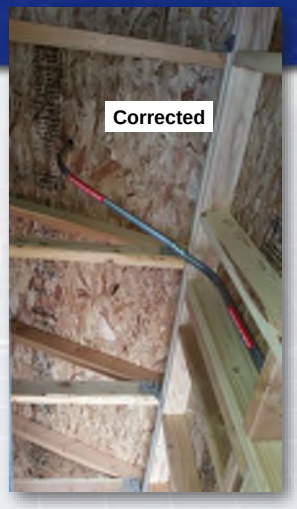

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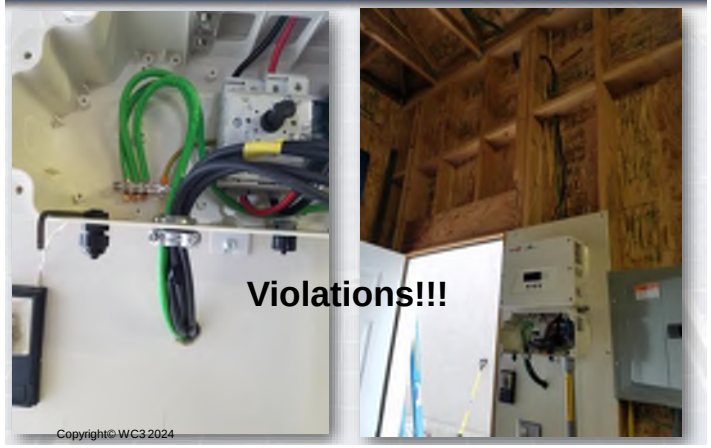
Conduit required for the conductors!



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Bonding of conduits

A bond bushing is required for metal conduit when the conduit is not bonded to a properly grounded metal enclosure. *NEC* 250.134.

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Bonding of conduits (continued)

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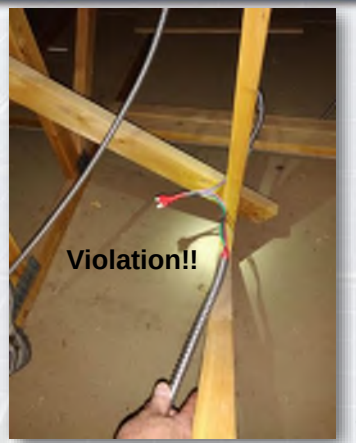
Junction Boxes



Junction boxes or enclosures are required for any splicing of conductors. *NEC* 300.15

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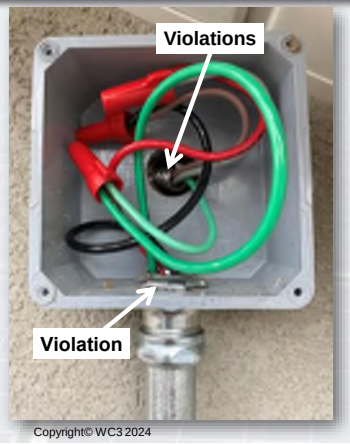
Bonding Sheath of MC Cable



Example of possible connectors to bond the sheath of the MC cable to the equipment grounding conductor (see exceptions of *NEC* 314.3):

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Supporting of Conduit is Required!

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Lots of Violations!!

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PV Signage

Photo from Instagram.com

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Signage, Per *NEC* 110.21(B)

- Signs must be durable and be able to handle the environment they are installed in.
- Signage cannot be hand-written.
- The markings must adequately warn of the hazard using effective words and/or symbols.

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Signage at Service Equipment

A sign is required at the service equipment to include the words "CAUTION: MULTIPLE SOURCES OF POWER." *NEC* 705.10.

CAUTION: MULTIPLE SOURCES OF POWER
(an[redacted] phone number of off-site entities servicing the system)

The sign must also note the location of all power production disconnecting means for the premises. *NEC* 705.10.

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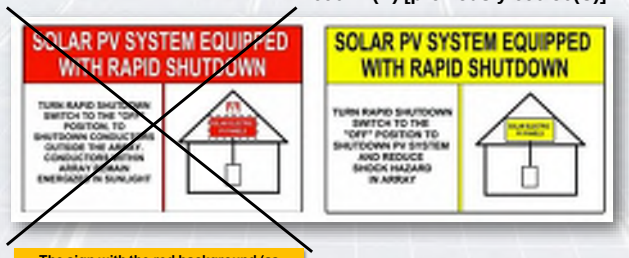
Rapid Shutdown Signage

Rapid shutdown sign required per *NEC* 690.12(D) [previously 690.56(C)].



The sign with the red background (as shown above) has been removed from 2020 *NEC* 690.56(C) as a required sign.

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Rapid Shutdown Signage

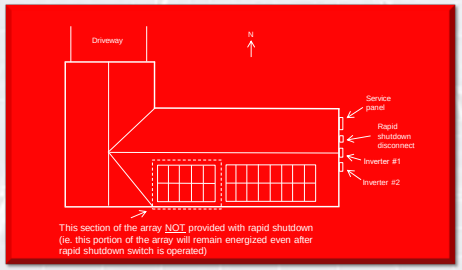
690.12(D)(1) [previously 690.56(C)(1)] Buildings with More Than One Rapid Shutdown Type:

- For buildings that have PV systems with **both** rapid shutdown types **or** a PV system with a rapid shutdown type and a PV system with no rapid shutdown, a detailed plan view diagram of the roof shall be provided showing each different PV system and a dotted line around areas that remain energized after the rapid shutdown switch is operated.

304

Rapid Shutdown Signage

Example of a plaque showing which portion(s) of the PV system are equipped with rapid shutdown and which are not:



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Rapid Shutdown Signage

- **690.12(D)(2) [previously 690.56(C)(2)] Rapid Shutdown Switch.** A rapid shutdown switch shall have a label located on or no more than (3 ft) from the switch that includes the following wording: **"RAPID SHUTDOWN SWITCH FOR SOLAR PV SYSTEM"**
- The label shall be reflective, with all letters capitalized and having a minimum height of 9.5 mm (3⁄8 in.), in white on red background.

Rapid Shutdown Switch
For Solar PV System

Sign located next to the rapid shutdown disconnect (and must be reflective)

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Sign at Point of Interconnection

Per the 2020 and older editions of the *NEC*, a sign is required at the point of interconnection noting the rated AC output current (amps) and AC voltage of the inverter(s). *NEC* 690.54.

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Signage at PV Backfed Breakers

If the 120% rule of *NEC* 705.12(B)(2) is utilized and the breaker is located at the end of the panel, a sign is required saying not to relocate such breaker.

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Sign at String Inverters

A sign is required at a string inverter, or distribution equipment associated with the PV system, giving the maximum DC voltage of the PV system. *NEC* 690.7(D) [previously 690.53].

Maximum DC Voltage = 600V

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Wiring Methods

690.31(D)(2) – Markings/Labels:

- There must be provided labels on the exterior of all exposed raceways, enclosures, boxes, and conduit bodies. The wording of the labels must state either of the following: "PHOTOVOLTAIC POWER SOURCE" or "SOLAR PV DC CIRCUIT."

PHOTOVOLTAIC POWER SOURCE

Or

SOLAR PV DC CIRCUIT

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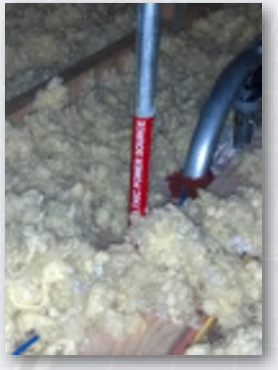
External Identification Of DC Wiring



Install by Intermountain Wind and Solar

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External Identification Of DC Wiring

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Warning Signage

***NEC* 690.13(B):**

- A sign is required at any disconnect or electrical box where both sides of terminals can be energized in the open position and must state:

WARNING ELECTRIC SHOCK HAZARD TERMINALS ON THE LINE AND LOAD SIDES MAY BE ENERGIZED IN THE OPEN POSITION.

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AC disconnects

Here is an example of an AC disconnect switch (used for a PV system) that would require the following sign:

WARNING ELECTRIC SHOCK HAZARD TERMINALS ON THE LINE AND LOAD SIDES MAY BE ENERGIZED IN THE OPEN POSITION.

NOTE: It's STRONGLY recommended that only AC disconnects with dead-fronts be used for a PV system or provide a lock for the disconnect!

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QUESTIONS

ANYONE?

Doug Smith, MCP, CBO
Cell: 801.550.7630
Office: 801.547.8133
Email: dougs@wc-3.com

315